The Physicists' View of Nature

Part 2

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The Physicists' View of Nature, Part 1: From Newton to Einstein

The Physicists' View of Nature
Part 2
The Quantum Revolution

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To
my wife Uma
with love

Preface and Acknowledgments

Physics textbooks for nonscientists, even today, seldom address questions that are of relevance to nonscientists, such as questions of meaning, values, creativity, and spirituality. This is in spite of the fact that the theory of relativity and quantum physics have made major impacts on such questions of philosophy.

Several years ago, I initiated the teaching of a course entitled "The Physicists' View of Nature," under the auspices of the University of Oregon Physics Department, to specifically introduce questions of meaning in our presenting of basic physics to nonscientists. The course has been highly successful and eventually led to the writing a two-volume book by the same name. The first volume, subtitled From Newton to Einstein, deals with classical physics and has already been published. This is Volume II of the book and it deals with the quantum revolution.

Besides covering the standard material, I have extensively discussed questions that intrigue the nonscientist: What is the relation of physics and biology? Why is mathematics important to physics? Does physics have something to say about consciousness, about values, about meaning? Can one integrate the worldviews of scientists and nonscientists? Can we ask the question of the existence of God within physics? What is the nature of creativity, scientific or otherwise? I hope the answers are stimulating and will even be satisfying to most students.

I would like to acknowledge the many discussions with my nonscientist students who took the course at the University of Oregon. Many thanks are due to Eve Brant who has done practically everything to bring the book to print. Finally, I would like to give sincere thanks to Sidney Solomon and Raymond Solomon, without whose encouragement the book would never have been written. I thank you all.

—A. G.
May, 2001

Contents

PART ONE
INTRODUCTION *1*

Chapter 1
From Classical Physics to Quantum Physics: A Still Aborning Paradigm Shift *3*
Anomalous Data *4*
What Is Quantum Physics? *5*
The Submicroscopic World *5*
The Radicalness of Quantum Physics *6*
Paradigms and Paradigm Shifts *8*

Chapter 2
Can We Determine the Metaphysics Underlying Reality? *11*
Dualism *12*
Holism *12*
Monistic Idealism *13*
Bridging Science, the Arts and the Humanities, and Spirit *14*
Experimental Metaphysics *15*
In Summary *17*

PART TWO
THE BEGINNINGS OF QUANTUM PHYSICS *19*

Chapter 3
Planck Takes a Quantum Leap *21*
The Energy Quanta of Max Planck *24*

Chapter 4
Einstein's Photons *29*
Wave-Particle Duality of Light *24*

Chapter 5
The Bohr Atom *35*
Atoms and Philosophy *39*

Chapter 6
The Discovery of Quantum Mechanics *41*
Wave-Particle Duality of Matter *43*

Heisenberg's Discovery 45
The Schrödinger Equation 45

Chapter 7
Possibility Waves, Uncertainty, and Complementarity 47
Probability and Uncertainty 52
Probability, Indeterminacy, and Acausality 54
More on Uncertainty 56
Wave-Particle Duality and Quantum Measurement 59
The Correspondence Principle 61

Chapter 8
The Copenhagen Interpretation 65
Cutting Through Classical Prejudices 66
The Dancing Wu Li Masters 68

PART THREE
QUANTUM PHYSICS COMES OF AGE 71

Chapter 9
Atoms and Light 73
Absorption Spectra 76
Fluorescence 76
Do Blondes Have More Fun? 77
The Laser 77

Chapter 10
Atoms and Chemistry 85
The Quantum Explanation of the Periodic Table 87
Pauli Principle in the Stars 91

Chapter 11
The World of Nuclei 93
Nuclear Stability 97
Nuclear Fission 99
Nuclear Structure 100
An Application of Nuclear Physics: A Revolution in Geology and Archeology 103

Chapter 12
Elementary Particle Physics: The Quest for Elementarity 107
The Particles and Their Interactions 110
The Quarks: The End of the Quest? 111
A New Picture of the Forces 113

Chapter 13
More Quantum Technology: Solid State Physics 119
The Carriers of Electricity 119
Energy Bands in Solids 120
The Solid-State Rectifier 123
The Solar Cell 125
The Transistor 125
Quantum World at a Glance 126

PART FOUR
THE PARADOX OF THE QUANTUM *129*

Chapter 14
Quantum Nonlocality *131*
Singlet Bohm, Singlet Bell *133*

Chapter 15
The Paradox of Schrödinger's Cat *139*
Bohm's Hidden Variables *141*
The Copenhagen Interpretation,
the Classical/Quantum Dichotomy, and Macrorealism *142*
The Many Worlds Theory *143*
Transactional Interpretation *145*
In Summary *146*

Chapter 16
Speculations About the Brain: Consciousness Within the Quantum *147*
Consciousness and Interconnectedness *149*
About Neurons *151*
Does Self-Consciousness Arise from Quantum Coherence of the Brain? *153*
Quantum Gravity in the Brain? *155*

PART FIVE
QUANTUM WITHIN CONSCIOUSNESS *159*

Chapter 17
Consciousness Enters Physics *161*
Who or What Collapses the Wave Function? *162*
The Paradox of Dualism *164*
Who Is Correct—Bohr or Von Neumann? *166*

Chapter 18
The Idealist Interpretation *167*
Monistic Idealism *169*
Quantum Measurement and the Nature of Consciousness *171*
Dualism *172*
The Apparent Subject-Object Duality *172*
The Epistemological Question *174*

Chapter 19
A Summary Tour of Quantumland *177*
Uncertainty and Potentia *178*
Consciousness and the Quantum *179*
The Double-Slit Experiment *181*
Schrödinger's Cat *183*
How Does the One Become Many? *188*

Chapter 20
From Deep to Deeper to Deepest Ecology *189*

Chapter 21
The reconciliation with David Bohm's Physics *193*
Implicate and Explicate Order *195*

Chapter 22
The Gifts of Quantum Physics *197*
The Discontinuity of Creativity *198*
Nonlocality *199*
Downward Causation *204*
Tangled Hierarchy *205*

Chapter 23
Quantum Creativity *207*
Situational, Fundamental, Inner, and Outer Creativity *207*
The Quantum Nature of Creativity *208*
The Creative Process and the Importance of Unconscious Processing *210*
Creative Encounter With the Quantum Self and the Flow Experience *211*
Creativity and Development *213*
The Role of the Unconscious *214*
Inner Creativity *214*

Chapter 24
Integrating Dualities *219*
Quantum Measurement Theory *221*
Life-Nonlife Duality *222*
The Mind-Brain Problem: A New Psychophysical Parallelism *222*
Conclusions *226*

Chapter 25
Quantum Cosmology and Consciousness *227*
Self-Reference and the Origin of Life *228*
The Delayed-Choice Experiment *229*
The Strong Anthropic Principle *231*
The Arrow of Time *232*

PART SIX
QUANTUM BIOLOGY–
HOW CONSCIOUSNESS CREATES BIOLOGICAL ORDER *235*

Chapter 26
Anomalies in Biology and the Need for a Paradigm Shift *237*
The Need for Biology Within Consciousness *241*

Chapter 27
Toward a Paradigm Shift in Biology *245*
Inside a Living Cell *247*
Neo-Darwinism *248*
Reductionism and Holism *248*
Self-Reproducing Automata and the Game of Life *250*
Chaos Theory *252*

Chapter 28
What Is Life? *255*

More on Purpose 257
The Creative Purpose of Consciousness 259
Consciousness and Order Within Chaos 260
The Question of Causal Efficacy of Life 262
Consciousness As the Creative Organizing Principle of Life 265

Chapter 29
The Quantum Theory of Punctuated Equilibrium 269
A Review of Existing Theories of Quantum Evolution 271
Comparison With the Case of the Brain 274
Apparent Purposiveness and Directionality in Evolution 276
The Nature of Life 277

Chapter 30
Evolution and Morphogenesis 279
Sheldrake's Theory: How Form Is Remembered 280
Who Programs? 281
Avoiding Dualism in Biophysical Parallelism 283
Nonlocality in Morphogenesis 285
Evolution and Morphogenesis 285
Regulation and Regeneration 286
Quantum Healing 287

Chapter 31
Creativity in Biological Systems 289
Directed Mutation 290
A Quantum Epigenetic Model 291
Explaining Phenocopies Within Neo-Darwinism 294
Rubin's Experiments: Heterogeneity and Creativity 296

PART SEVEN
OUTLOOK 299

Chapter 32
Consciousness and Evolution 301
The Theme Body or the Body of Intuitive Knowledge 304
Science and the Great Chain of Being 304
How Far Evolution? 307

Chapter 33
The Challenge of Trans-Modernism 311
The Dance of Gaia 312
The Driving Principles of Trans-Modernism 312
The Question of Spirituality in Human Affairs 318
The Evolution of Human Society 319

Chapter 34
Epilogue: God and the Physicists' View of Nature 321

Glossary 331

Index 339

Part ONE

INTRODUCTION

CHAPTER 1

From Classical Physics to Quantum Physics: A Still Aborning Paradigm Shift

Classical physics is the physics that Isaac Newton built some 350 years ago. It gave us the idea that objects of the world follow a mathematical prescription independent of us, the subjects; indeed, the entire reality is independent of us and is objective. Classical physics has also given us a view of the world that is mechanistic, deterministic, and materialistic.

The idea of a *mechanistic* world is that the world is machine-like, its changes and movements are continuous, describable by algorithms, step-by-step mathematical procedures. The philosophy of *determinism* holds that every movement of every object in the world can be determined from the laws of physics, once we know some of their initial conditions. Finally, materialism is the idea that the world consists of matter and its correlates, energy and force fields, and is reducible to basic building blocks, the elementary particles, and their interactions. In materialist philosophy, formally called *material realism*, all causality in the world comes from elementary particles and their interactions, which are the ground of all being. Elementary particles make atoms, atoms make molecules, molecules make cells (including neurons), neurons make the brain. The brain makes us, but underneath we are the play of the elementary particles, the product of the *upward causation* due to their interactions.

This view of ourselves is conceptually very bleak because if we lack causal efficacy it is hard to ascribe any meaning to our endeavors that include science. Some scientists unabashedly resign themselves to this meaninglessness of the universe. "The more the universe seems comprehensible, the more it seems pointless," says the Nobel laureate physicist Steven Weinberg. Others look for a way out of this conceptual dark alley.

A. Goswami, *The Physicists' View of Nature*
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Quantum physics, sometimes called the new physics (in contrast to the "old" classical physics), began with the idea of the quantum—a discontinuously discrete quantity. As such, quantum physics insists that movements of the world are not only continuous but also discontinuous. What this means is that not all movement has causal continuity, causal explanation in terms of upward causation. Quantum physics is revolutionizing our worldview by opening a window—the window of discontinuous movement—through which the light of consciousness is entering physics and illuminating all of its conceptual darkness. This book is about this quantum revolution.

Anomalous Data

Classical physics deals with the movement of macroscopic bodies, bodies of large mass and bulk around us. Toward the end of the 19th century, physicists began investigations into the world of the submicroscopic constituents of macrobodies. And almost immediately, anomalous data were revealed that violate one or more of the fundamental principles of classical physics. At the turn of the 19th century, the physicist Lord Kelvin was supposedly asked about the future of physics, to which Kelvin gave the famous reply that physics is a finished product except for a couple of little things that would soon find explanation. One of these little things was the anomalous data regarding how radiation is emitted from incandescent bodies, the eventual explanation of which led to the idea of the quantum, to the overthrow of the classical principle of continuity, and to the development of quantum physics (see Chapter 3).

Another anomaly that showed up is radioactivity: certain chemicals spontaneously emit radiation. The law of this emission is probabilistic, not deterministic. We cannot predict when a particular emission will take place, but only the probability of that emission. Thus the classical physics idea of strict determinism is violated.

In the 20th century, physicists gained the technology for investigating the heart of matter, atoms, and even their constituents, the elementary particles. Investigations revealed further anomaly; in truth, classical physics was found to be unable to explain even the simple fact of atomic stability—why the atoms around us that make up the bodies of our macroworld are stable. You know the basic picture of the atom: light elementary particles called electrons orbit the relatively heavy central core called the nucleus of the atom. But according to classical physics, orbiting electrons must lose energy via the emission of electromagnetic radiation. Thus, their orbits must shrink and eventually the electrons must fall into the nucleus. In this way the atom of classical physics is unstable, contradicting our experience.

Classical physics cannot explain an important order established in chemistry. There is an orderly arrangement of the chemical elements, called the periodic table, which was discovered by the chemist Dimitry Mendeleev. But no explanation of this kind of regularity can be given using Newton's laws of motion. It is not at all clear why such regularity should exist.

The list here is not complete. What became clear at the tail end of the 19th and in the beginning of the 20th century is that the complacency and certainty of classical physicists regarding the success of their physics (as voiced by the legendary statement by Lord Kelvin)

came from incomplete knowledge. So long as we keep to the study of macrobodies, classical physics seems to work well. But this old physics does not work at all in the submicroscopic world, the investigation of which would become one of the specialties of the 20th century.

What Is Quantum Physics?

What, again, is quantum physics? We will develop a fuller answer later, but for now, suffice it to say a few things to reveal the revolutionary nature of quantum physics. Etymology will not be of much help here. The word *quantum* originates from a Latin word meaning quantity. The word was first used to signify a discrete quantity of energy, angular momentum, and other such physical quantities. So, in finer examination of the law of emission of radiation from radiant bodies, energy is found to be exchanged in discrete lumps, the energy quanta; energy is not indefinitely continuous, it cannot be broken down to arbitrarily small amounts. So at the base level of things, in the submicroscopic world, matter clearly exist as discrete bundles of energy, charge, angular momentum, and so forth; these are the elementary particles. From this beginning came the huge ideas of atomic, nuclear, solid state, and elementary particle physics that gave us lasers, atomic bombs, transistors, giant atom-smashing accelerating machines, and more. It gave us a new way of looking at reality.

One thing before you delve into the submicroscopic world. Recently, several books have come out with titles like *Alice in Quantumland* with the idea that the land of quantum physics is like the wonderland that Alice explored. Remember Alice's tree? Classical physics explores things above ground, where the tree is, where we can see the results of our measurement. Even the measurement of the submicroscopic roots of the macroworld requires the amplification of macro apparatuses, seemingly bound by the rules of classical physics. We never see the submicroscopic world directly, you know. How should we explore the roots, then, since empirical investigation is limited? We have to trust our theories and the philosophies we use to interpret our theories. Most of all, we, and you, too, dear reader, have to go down the "rabbit's hole" of imagination to where the roots are. Then, and then only, we will get to the juicy part of quantum physics.

The Submicroscopic World

In classical physics, we do have the concepts of atoms and molecules, and even that of elementary particles such as electrons, and these concepts have greatly helped in developing a successful reductionist picture of thermal physics and the physics of electricity and magnetism, for example (as you have amply seen in Volume I of this book). With new breakthroughs in experimental technology in the 20th century when it was possible to delve deeply into the heart of matter, we began to be more acquainted with our postulated objects—molecules, atoms, and elementary particles. And there came many surprises.

The first surprise was, as mentioned already, that some of the ideas of classical physics do not work in this new realm of physics and new ideas have to be introduced. Above

I mentioned the breakdown of the principle of continuity in the exchange of energy in the phenomenon of radiation from incandescent bodies, and the introduction of the energy quanta—discrete bits of energy—but that is just the tip of the iceberg. When the idea of discreteness and quanta was introduced in our theories of the atom, the problem of emission of light from atoms became tractable—so much so that we have managed to manipulate it to make the emission in special cases very special, laser light for example (see Chapter 9). The discrete nomenclature of the states of the atom solved the anomalous problem of the periodic table in chemistry as well (see Chapter 10).

A second surprise. The movement of quanta was found to be shrouded by a cloud of uncertainty, which gave rise to some strange phenomena. Electrons and other subatomic particles are able to jump over hurdles, even though they don't have enough energy to jump. They can borrow some energy, taking advantage of the uncertainty in maintaining nature's energy ledger. This barrier penetration ability of the electrons, when suitably manipulated, gave us the new and wonderful technology of the transistors, beginning the solid state revolution that includes our precious computers (see Chapter 13).

Uncertainty breeds probability. This probabilistic behavior explained the anomaly of radioactivity—radioactive decay is probabilistic. Radioactivity involves the core of atoms—atomic nuclei. How do parts of the nucleus escape the bondage of the rest spontaneously? Barrier penetration, again, is the answer (see Chapter 11).

A third surprise. A novel change took place in how we look at forces and force fields between elementary particles. The idea was developed that the force fields themselves consist of quanta, and a force happens when these quanta are exchanged between two bodies. This way of looking at force fields began a program of unification of physics via a unified way of looking at all the fundamental forces between material objects that nobody could have guessed except Einstein (although in a different context). This program defines the heart of today's research in elementary particle physics (see Chapter 12).

The Radicalness of Quantum Physics

But all these surprises seem to be esoteric, only appreciated in the context of physics and its problems. The idea of quanta alone does not seem to be *that* radical conceptually, at least to the nonspecialist. You don't see yet why this idea forces you to abandon your very way of thinking about the world.

Let me try to give you a quick introduction to the radicalness of quantum physics in a few paragraphs. You know that physical laws of motion enable us to solve the fundamental question of movement of an object: Where is the object when? Classical physics is deterministic because it exactly tells us where an object is when. But quantum physics equivocates. It gives us probabilities that an object should appear in some possible places, but says nothing more definite. So at first people thought that quantum physics was probabilistic, and it applied only to large ensembles of objects, not to the objects themselves. It was a little disappointing, but certainly one could make do. In atomic and subatomic physics, where quantum laws are necessary in order to explain the anomalous data referred to above, we almost always have large ensembles of objects. You remember that a spoonful of a substance has some 10^{23} atoms in it.

But detailed analysis of experimental data revealed the possibility of revolutionary radicalness—the quantum laws do apply to individual objects. The motion of every quantum object must be depicted as a wave of possibility, a superposition of many possible actualities. Gone is the unique-actuality depiction of Newtonian physics. An electron is a possibility object with calculable probabilities to manifest in this, that, and the other place at this time. This is what the laws of quantum physics enable us to figure out: the possibilities and the probabilities associated with each possibility.

Now the radicalness. When we do experiments with quantum objects, we do not find the objects smeared out in all those possible places of quantum prediction, but instead quite actualized in only one of its possible places, much like Newtonian objects. To be sure, if we do many experiments, the object shows up actualized in all of its possible places with probabilities that agree with quantum calculations. But quantum mathematics cannot predict the outcome of a single measurement event. So how do we connect quantum theory with experiment? A postulate—called the measurement postulate—is necessary as part and parcel of quantum physics. Our observation collapses the quantum wave of possibility to a unique particle of actuality or, using slightly different words, our experiment reduces the superposition of many possibilities (technically called a wave function) to a unique actuality. There is no mechanism for collapse, no algorithm for it can be given, no causal description. The collapse of the quantum wave of possibility is truly a discontinuous affair and *we* have something to do with it.

I hope you now see the radicalness of quantum physics. Who or what collapses the quantum possibility wave into one actuality from behind the veil of discontinuity? Who or what considers these possibilities and chooses from them? This kind of question can most easily lead to seeing a role for the observer, a genuine observer effect, or an effect that consciousness imposes on objects. A consistent answer to the question of collapse is this: quantum possibilities are possibilities within our consciousness, and consciousness chooses the unique actuality from the possibility spectrum in each event of quantum measurement. Since there is no mechanism, no algorithm for the event of discontinuous collapse, the choice can be free—it can be creative! So not only does consciousness enter physics, but free will and creativity do as well.

So this is the radical message of quantum physics. Elementary particles and their interactions, upward causation, are important for shaping the world around us, no doubt. But upward causation produces only possibilities within consciousness. Consciousness has the power of *downward causation* to choose among the possibilities and make actualities of the world that we experience.

In summary, there is continuous and deterministic movement in quantum physics, the development of waves of possibility in time. The general acceptance of quantum physics as the ultimate physics of matter comes from its ability to predict this aspect of quantum movement with unprecedented accuracy. But there is also discontinuous movement, the event of collapse. For this, there is no mathematics, no algorithm for prediction. Here consciousness is needed, and free will and creativity find room.

But it is a long way from here to show that consciousness, normally regarded as a concept of neurophysiology and psychology, is really needed in the quantum context, to solve the problem of discontinuous quantum collapse. Should we let ideas of neurophysiology and psychology invade physics, while physics has long been regarded as the funda-

mental science, and biology and psychology regarded as derivable from physics? Moreover, what is consciousness? Do we even understand it in the biological and psychological context? Can we define it?

This kind of questions has held us up for a long time from investigating the truly radical consequences of quantum physics, consequences not only in the domain of physics, but also in the domain of biology and psychology. The answers to these questions that will emerge during the course of this book are also radical. Consciousness is not a product of our biology and psychology; instead, it is the ground of all being, including biological and psychological beings. This overarching role of consciousness as the ground of being of physical as well as biological and psychological beings will be found to hold the key to a unification of physics with biology and psychology (see Parts 5 and 6).

I submit that consciousness is the correct context for looking at the quantum measurement postulate. And more. When we understand the quantum within consciousness, we are also able to build a bridge between science and the rest of human endeavors—art, music, humanities, even the spiritual (see Chapter 2).

Paradigms and Paradigm Shifts

The philosopher Thomas Kuhn introduced the very important idea of *paradigm*. A paradigm is a supertheory that acts as an umbrella under which, at a given time, scientific theories are developed and experiments are conducted within a given field of endeavor. In time, as the arena of investigation of the given field expands, the paradigm develops a few chinks in its armor in the form of logical inconsistencies or paradoxes and anomalies—anomalous data that it cannot explain. Then we have a paradigm shift to a new paradigm that explains all the anomalous data, and logical consistency prevails once again.

In Volume I of this book, I have already sung the glory of the successes of the old paradigm, classical physics. However, as mentioned above, in time this very successful paradigm has also developed certain signs of incompleteness. There are anomalous data in the domain of submicroscopic objects. This is what opened us to the new paradigm of quantum physics, an understanding of which requires the entry of consciousness in the arena of physics.

There are also paradoxes in classical physics thinking even for the macroworld of its successful application. These paradoxes were discussed in Volume 1. To review a few:

The Paradox of the Relation of Mathematics and Physics

Why is physics mathematical? If everything is movement of matter, then the laws of physics also should derive from the random movement of matter. Instead we have mathematics, we even have the criterion of beauty, a conscious experience, for discovering the mathematical laws of physics. This is a paradox.

The Paradox of Becoming

Classical physics is essentially a physics of being. The laws of movement in classical physics do not distinguish between the past and the future; they do not define the arrow

of time. But empirically, we have the second law of thermodynamics—entropy or disorder always increases (or at best stays the same). This defines the entropy arrow of time as the time direction of entropy increase. By noting that the entropy has increased we can distinguish between the past and the future.

Empirically, we also have biological evolution of more and more complex living beings with time, giving us the biological arrow of time as the time direction of increasing complexity of life. There is not necessarily a conflict between the two arrows of time because locally, the entropy may occasionally decrease (more complexity translates as more order, less disorder, a decrease of entropy), and yet the overall entropy may always increase. But the biological arrow of time also does not follow from Newton's laws of motion.

The Paradox of Life and Consciousness

Can classical physics act as the foundation of biology, the science of life? There is a paradox here because consciousness must be defined to incorporate the quality called the subject, the experiencer, whereas classical physics talks only about objects. Another way of seeing this is as follows. Classical physics is algorithmic, based on continuity and a bit-by-bit mathematical way of calculation. With algorithms, input statements always lead to output statements, object leads to object, not a subject cognizing an object.

But cognition, the subject-object split of experience, not only defines an important aspect of consciousness, but also may define life itself, as suggested by the biologist Humberto Maturana.

So how to introduce experience, with both its subjective and objective aspects, remains a paradox in classical physics. Some philosophers, notably David Chalmers, have called this the "hard question" of consciousness research.

I hope you see that the discussion of the paradoxes of classical physics is leading us to the same conclusion: consciousness is an important ingredient of reality that classical physics is unable to include. Quantum physics, however, gives us a window of opportunity to include the proper role of consciousness. We will see later that when we develop a science within the primacy of consciousness, the paradoxes of classical thinking are resolved.

Bibliography

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Putnam/ Tarcher, 1995

Wolf, F.A. *Taking the Quantum Leap*. San Francisco: Harper & Row, 1981.

CHAPTER 2

Can We Determine the Metaphysics Underlying Reality?

The classical physicist's view, with its roots in the 17th century physics that matured under Isaac Newton, has influenced biology and psychology, an influence that began in the 19th century and still continues, although somewhat abated. The most devastating consequence of this metaphysical view (called *material realism*) of biological and psychological beings, which includes us, is that all our subjective experiences, indeed, our minds and consciousness, are regarded as meaningless epiphenomena of matter–only matter is real. This means that the dance of the elementary particles of matter is the real thing; mind and consciousness are merely ornamental, having no causal efficacy. "A physicist is [merely] an atom's way of knowing about atoms," says the classical physicist. (The biologist puts this epiphenomenalism slightly differently; "A human being is a gene's way of knowing about genes.")

But this myopic view does not jibe with the experience of the people of the arts and humanities. There would be no art, none of the disciplines of the humanities, if all our subjective endeavors lacked meaning, value, and causal efficacy. And the materialist view of the world squarely contradicts the worldview of spiritual traditions, still quite popular even among scientists. The spiritual traditions of the world continue to uphold the belief that the world is fundamentally spiritual–the kingdom of God is everywhere, to paraphrase Jesus, although people don't see it readily. But people do see the causal efficacy of matter and machines readily, and this increases the confusion.

How do you, dear reader, think of yourself? Are you at ease thinking of yourself as a material, determined machine, as a meaningless dance of quarks and electrons? How do physicists and other scientists think of themselves? I always like to tease my materially oriented scientist colleagues: "If you believe yourself to be determined material machine, basically a zombie, why do you take yourself so seriously?"

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But bantering goes nowhere because the physicist can easily retort that taking ourselves seriously is also part of the meaningless ornamental extravagance that we are!

Dualism

In truth, the reason we all tend to take ourselves seriously, the materialist view propounded by physicists notwithstanding, is that we are hidden dualists. Descartes long ago gave us the philosophy of modernism, in which the world is a machine, but the mind is not. Mind is a dual world separate from the machine world; it has free will; it can control the machine world of things by discovering that world's mechanical laws and manipulating them. We take ourselves seriously because we are these thinking minds. "I think, therefore I am."

But dualism is hard to uphold because if mind and matter are two separate things, separate substances comprising separate worlds, how do the two interact? Think about it. Two things that have nothing in common cannot directly interact. They need a mediator. But where is this mediator? In our experience, there is an internal component and an external component: we call the internal mind and the external we see as the playground of matter. It sure does not seem that there is a third mediator substance anywhere.

On top of this difficulty with dualism, the resounding success of classical physics in explaining the external material world opens us to the parsimonious hypothesis that it is all matter, including the interior mind. This is the philosophy of epiphenomenalism.

Epiphenomenalism, taken seriously, leads to a deep despair of spirit. This is the origin of much of the post-modern malaise that we see around us—in our art, in our culture, in our politics and media. We seem to be in a pit of meaningless extravaganza, and there seems to be no way out. We cannot win. If we believe in modernism, we contradict what physicists and other scientists are telling us. If we believe that we are materialist machines, then nothing matters. A scientist was asked, "What's mind?" He said, "Doesn't matter." And when asked, "What's matter?" he quipped unabashedly, "Never mind."

Holism

Along came some optimistic post-modern thinkers and a new philosophy called holism was born. This is the idea that the whole can be greater than the sum of the parts. The parts and their interactions, when things become very complex, perhaps give rise to a whole that does have causal efficacy, does have meaning, does have interconnectedness that we can identify as spirit, as the kingdom of God, or consciousness.

Instead of reductionistic physics that gives us existential despair, should we not opt for this holism, this "Tao of physics?" A recent advance of physics, chaos theory (see Volume I of this book), seems to support the idea of emergent holism. Chaos theory works within the ideas of mechanism, determinism, and materialism; but it is founded on a recently discovered surprise that many mechanistic systems are determined, but not so much predictable. For such chaotic systems (weather is a good example), the butterfly

effect holds: a little dance of a butterfly in one part of the system affects parts of the system far away. Notice how close this is to what the mystic poet Francis Thompson wrote:

> All things by immortal power
> Near or far
> Hiddenly
> To each other linked are,
> That thou canst stir a flower
> Without troubling of a star.

A Zen dialog between a student and a master has the same flavor as Thompson's poetry. "Master, from where comes your spiritual power?" asks the student. The Zenmaster replies, "By being connected to the source." "You are connected to the very source of Zen?" retorts the student with not a little incredulousness. "Yes. And beyond that. I am Zen. The connection is complete," replies the master nonchalantly. "But isn't it arrogant to claim complete connection with the source?" The student is still incredulous. "On the contrary," says the master. "Everything is connected. If you think you are not connected to the source you are thumbing your nose at reality itself."

So does realizing the "Tao of physics"–the interconnected wholeness that holistic physics promises–restore the damped spirit of the post-modern world? Unfortunately, holistic emergence of causal efficacy and interconnectedness is totally unfounded from what we know of material systems and their interactions. Elementary particles make atoms, atoms make molecules, molecules make cells, cells (neurons) make brain. In this hierarchy of material things, we do not know much about the brain, and although molecular biology gives us much knowledge about the living cell, the knowledge is far from complete. But our knowledge of molecules and atoms is so complete that we can refute emergent holism with quiet confidence–why don't new holistic properties emerge at the levels of atoms and molecules that are not reducible to their constituents and their interactions? And chaos theory does not really help, because it implicitly accepts determinism. True, the lack of complete predictability may give us a pseudo free will, the appearance of a free will, but what is such appearance good for? We still don't have real causal efficacy.

So are we to become existentialists, asserting that only existence is and there is no essence? Perhaps metaphysical assertions are for the birds, why bother with metaphysics? But alas! Even this assertion is metaphysics!

Is there an alternative to materialism, dualism, and no-metaphysics-ism (for which the technical name is logical positivism)? There is. This philosophy holds consciousness as the primary being and is called monistic idealism.

Monistic Idealism

The point is this. We undoubtedly have an interconnectedness, but is this interconnectedness explainable with the holistic notion that everything interacts with everything else, nothing is truly isolated in view of the fact that some of the forces of

nature have infinite outreach? Monistic idealism has a different track to interconnectedness. Here all things are interconnected nonlocally through consciousness, not through force fields and signals. This is what the Zenmaster in the episode above calls "the source."

What is consciousness? We can start the discussion with what it is not. It is not part of the mind-matter, internal-external, duality. It is not an object, although objects appear in it. It has also to do with the subject, the experiencer, the knower of objects.

But the knower and the known, subject and object—isn't this another kind of duality? The philosophy of monistic idealism avoids this trap by declaring that consciousness, the source, the whole, the ground of being, is nondual; there is no split in it whatsoever. All duality, including the subject-object duality, is appearance only.

What is consciousness? Because consciousness is the ground of being, all else, including words, concepts, and metaphors, are secondary to it. We cannot define consciousness completely with items that are secondary to it, accentuating the mystery. But, say the spiritual sages, the discoverers of the monistic idealist philosophy, although we cannot define it, we can be it, we are it. It is our ignorance that is preventing us from seeing our original nature, our interconnectedness with the source.

There is another way of seeing this. There are three aspects of our everyday experience that point to consciousness. The first is existence. We exist; we don't need a doctor to tell us we exist, we are alive. The second aspect is awareness, our ability for subject-object split experience. And the third is bliss or happiness. Materialists think that our happiness comes from material objects, but only a little self-study will convince you that happiness is an intrinsic inner phenomenon; external sensory objects may trigger it, but they are neither necessary nor sufficient. The origin of bliss is our interconnectedness, our unlimited wholeness.

For interconnected wholeness of the local kind, we have chaos theory supporting it. Is there any supporting physics for this nonlocal interconnectedness through consciousness? There is. Quantum physics is radical in yet another respect. Besides the local interactions between material objects that take place through the exchange of energy or signals, in quantum physics there are also nonlocal influences that do not propagate via signals, that do not propagate through space and time at all. This quantum nonlocality is the supporting physics for the kind of nonlocal interconnectedness that consciousness presumably is.

Bridging Science, the Arts and the Humanities, and Spirit

The artists, the humanists, and the spiritually inclined among us have long recognized that their endeavors are nothing but adventures in consciousness, a sometimes roundabout way to search for our "souls." Once we see the metaphysical unity of all of our exploration, including science, the scientists, too, can join in the dance of reality, hand-in-hand with the artist, the humanist, and the mystic. But we should not be too hasty; otherwise the bridge thus built for the cross-cultural dance would only be temporary.

The scientists have a gripe that the artist, the humanist, and especially the mystic are guided by belief, in God, for example, that cannot be upheld via rational means and hard data, which is how science works. And from their side, the artist, the humanist, and the

mystic bitterly complain against science's total reliance on rationality and empirical data. They talk about intuition, and they invite the scientist to try other methods of knowing.

But this methodological debate is totally unfounded. I have shown in Volume I of this book, through several case histories, that scientists also use intuition in their discovery process, that scientific creativity involves a crucial stage called insight, in which neither empirical perception or sensing (hard data) nor reasoning (rational conceptualization) is involved. Instead, insight is obtained as a discontinuous movement of the mind. It should not take long for the reader to realize that what the artist, the humanist, and the mystic is calling intuition or other means of knowing, the scientist is already using. The creative methodology used in all human endeavors is the same.

Likewise, is the artist or the mystic propelled by belief? In the beginning of the journey in these enterprises a belief may be necessary. It is similar to the "initial hypothesis" of the scientist's strategy. But for the artist and the mystic, too, the proof of the pudding is not in the hypothesis, but in the eating. The artist, the humanist, and the mystic discover through their experiences the working of their hypothesized "God" in their lives. In other words, the methodology of all the endeavors under discussion is the same, although different languages are used to describe it, creating confusion.

Besides ontology (metaphysics) and methodology, there is also cosmology. We have an exterior and an interior awareness. Science works with the cosmology of the exterior. The artists, the humanitarians, and the spiritual seekers look inside for their exploration, and their cartography tends to concentrate on the inner landscape. This reminds me of a couple of cartoons. In the first one, a professor (male, of course) is being asked by a wide-eyed female admirer, "Professor, how do you know so much?" To this the professor smugly says, "I open my eyes." In the next frame, a Zen student is asking his Zenmaster a similar question, "Zenmaster, how do you know so much?" To this the Zenmaster, who is serenely meditating, replies, "I close my eyes."

How can we put together the findings of the two complementary approaches? This is obviously a great need for the life sciences, where neither exteriority nor interiority can be denied. Can we ever unite the conceptual basis of the life sciences, in which both exteriority and interiority must be valued, with those of physics, with its clear emphasis only on the exterior? We can't, so long we stay within classical physics. But with quantum physics within consciousness, we can. You will see the demonstration in this book.

Experimental Metaphysics

Quantum physics formulated within the philosophy of monistic idealism enables us to develop an integrated science of body, mind, and spirit, as we will see. But is this enough to suggest that monistic idealism is the correct metaphysics of reality?

The beauty of the current development of science is that today, as the philosopher Abner Shimony has emphasized, we can let experiments decide what is the metaphysical truth. Is the basis of our interconnectedness a holistic metaphysics or a monistic idealist metaphysics? This question is experimentally tractable because it can be translated into the experimental question, "Is our interconnectedness due to local or nonlocal influences?"

The neurophysiologist Jacobo Grinberg of the University of Mexico and his collaborators have done an experiment that sheds considerable light on this question, "Which way interconnectedness–holism or monistic idealism?" Grinberg et al instructed two subjects to meditate together with the intention that they have direct (nonlocal) communication for 20 minutes, an intention that the subjects were asked to maintain during the entire interval of the experiment. After the initial 20 minutes, the subjects were separated in individual Faraday chambers (electromagnetically isolated rooms) and their brains were attached to individual electroencephalogram (EEG) machines. Now, one subject was shown a series of light flashes, producing electrical activity in his or her brain that was measured by the EEG, from which the experimenters were able to extract an "evoked potential" upon eliminating the noise. The surprising element of the experiment is that there was significant electrical activity in the brain of the partner as well (although he or she did not see any light flashes), as recorded by the EEG machine, from which the experimenters were able to extract a "transferred potential" similar in strength and phase to the evoked potential. How is electrical activity in one brain transferred to the other brain without local connection? The answer is nonlocal interconnectedness through their conscious intention–consciousness.

The Grinberg experiment has now been replicated by neuropsychiatrist Peter Fenwick and his collaborators in England, giving further support to the idea that monistic idealism with consciousness as the nonlocal ground of interconnectedness of all beings is the correct metaphysics of reality.

Is Experimental Metaphysics of Any Practical Use?

Are you excited about the possibilities that the quantum revolution opens us to? In the summer of 1993, I attended my first biology conference, an informal conference arranged by the UC-Berkeley biologist Richard Strohman. At dinner one evening, a young biologist asked me what the selling point is of the new quantum paradigm of science based on the primacy of consciousness that I was proposing. "Well," I said, "it [the paradigm] resolves the paradoxes of quantum physics and of life and consciousness. It integrates physics with biology and psychology and science with spirituality. It treats subjects and objects on the same footing."

"That's too esoteric," dismissed my young friend. "The average person is not interested in the integration of physics and psychology, even spirituality. What else have you got?"

"The old science is about only the conditioned behavior of the world; the new paradigm also can handle the creative aspects of the world. Hence, it allows us to explore new avenues for our creativity. Surely, everyone is interested in creativity," I said.

"Maybe," my young friend allowed noncommittally. "What else have you got?"

Suddenly I understood what he was getting at. "You mean, is there an application of the new paradigm that is so striking that it will grab public imagination? There is. The new way of doing science not only may answer some knotty problems of biological evolution and morphogenesis [the emphasis of my talk at the conference], but may also be able to integrate the disparate ideas of conventional and alternative medicine (such as homeopathy, Chinese medicine including acupuncture, and Indian medicine–*ayurveda*)."

"That's the one, that's your communicating point to the public," said my new friend with enthusiastic approval.

My friend is right. Science is proper science (instead of being pseudoscience) when it fulfills two criteria. The first criterion is that of experimental verification. The second is that of useful and practical applications. The most important application of a consciousness-based science will be in healing and medicine, for the simple reason that healing is about regaining wholeness. Conventional medicine treats the material body but neglects the rest of the being. So this kind of practice of medicine cures disease but does not heal. When we bring consciousness back into medicine, medicine will once again become a science of healing (see Chapter 30).

It's not just healing where the new principles of quantum metaphysics will find application. I recently have addressed many groups of people in the business community about the question of how to bring values back in business, how to bring creativity and consciousness into business and technological pursuits. And I have seen real hunger in these groups for wholeness, for consciousness, for spirituality. In the last few centuries, while capitalism was in developmental stage, its success was possible because religion provided the values necessary. Now under material realism's persistent attacks these values have been undermined and conducting businesses has become more and more difficult. If you are not convinced that values are a necessary ingredient of capitalism, look at the debacle capitalism is facing in Russia, where communism got rid of religion even faster than the free world countries and their scientism. With quantum physics and monistic idealism to guide us, values will make a triumphant return in how we conduct our businesses and industries, but without religious baggage (see Chapter 31).

Here, then, dear reader, a book of physical and metaphysical ideas and experiments that will not only revolutionize your worldview, but also will promise new, useful applications of great social importance.

In Summary

I have given you a glimpse of what the quantum revolution is about, what this book is about. In the introduction to Volume I of this book, I promised that physics is relevant for your questions of meaning. I hope you can see it all now. Meaning is back in science, value is back in science, when science is fully established in consciousness.

Classical physics dealt with half of the apple of reality—the objective half. Quantum physics opens us to the other half—the subjective half. The revolution, however, is far from complete. There is much controversy about the proper interpretation of quantum physics; materialists continue to search for material alternatives (without success). But the debate is interesting and is part of the book. And ultimately, science is experimental. So the veracity of the new science, like the old science, must be founded on experimental data. New experiments that support the extended view of physics will be emphasized in this book.

Interesting, isn't it? In Volume I, I posited four philosophies, four possible ways to construct your worldview. Today, we have the opportunity to experimentally determine which philosophy is true blue, which gives the most useful description for our search for

meaning in our own lives. Abner Shimony has called this new enterprise experimental metaphysics. Others call this approach the approach of public faith, since the testing of metaphysical beliefs in the laboratory is tantamount to garnering public faith.

So we began the modern scientific journey trying to separate science from the grip of the Christian church. We became the modernist humans with big egos who proclaimed human over nature. Then came an epoch of post-modern revision when we saw ourselves as meaningless machines despairing in vain in our separateness. And now, once again, we resume our journey of reenchantment with the world. This is the greatest gift of the quantum revolution.

Bibliography

Grinberg, J., et al. "Einstein-Podolsky-Rosen Paradox in the Human Brain: The Transferred Potential." *Physics Essays*, vol. 7, pp. 422-428. 1994.

Part TWO

THE BEGINNINGS OF QUANTUM PHYSICS

CHAPTER 3

Planck Takes a Quantum Leap

At the end of the 19th century, a series of discoveries was made in physics that called for a change in our worldview, a change that is still going on. How did it all begin? Let's discuss the crucial piece of experimental data that refused explanation on the basis of then-current beliefs of physics.

Toward the end of the 19th century, the belief was growing that classical physics was the last word in physics, that it explained everything, except maybe one or two small things. Among these "small" things was the phenomenon of ***blackbody radiation***.

If you can see yourself as a physicist at the turn of the century, you must also see yourself interested in understanding the phenomenon of blackbody radiation—how hot objects emit radiation. But as a physicist of classical vintage, you'd look at every phenomenon with the Newtonian conceptual lens that the universe is a classical machine consisting of parts that move continuously according to Newtonian laws. You'd believe that once you had all the necessary information about the movement of the parts and if you could figure out a few glitches, a few unknowns about the laws these parts obey, then you would be able to predict the future of the universe forever. So you would be perpetually troubled by those few glitches; the Newtonian science you would have known could not have prepared you to answer such questions as, "What is the law of emission of radiation from hot bodies?"

Imagine that it is winter, and as you puzzle over this question with great concentration while sitting in front of a glowing fire, your loved one is slightly impatient with your lack of attention toward him or her.

A. Goswami, *The Physicists' View of Nature*
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Loved one: Pass me another pillow.

You (passing the pillow): I just can't see through this. I can't figure out why we are not getting a good tan right now.

Loved one: (laughing): Well, a tan would be great. You know how much I love to have a tan. Then we could even justify using the fireplace in the summertime.

You: You see, my theory (it is called thermodynamics, my dear) says that the radiation from the fireplace should be as rich in the high frequencies—that's ultraviolet, sweetie, the invisible light that tans you—as sunlight is.

Loved one (frowning, deep in concentration): Go slow. What's frequency?

You (seeing the frown on your loved one's face): What's frequency? You see, radiation consists of electromagnetic waves; frequency tells you how rapidly the waves wiggle. But what makes the sunlight, and not the light from the fireplace, rich in these high frequencies? Look at this radiation-distribution curve (Figure 3.1, dotted line), based on my classical physics. The intensity keeps going up at the high-frequency end of the spectrum irrespective of the temperature of the emitter, with no attention to the experimental data.

Loved one (teasing): I didn't get all of that, but tell me, have you ever taken the temperature of an emitter, a feverish emitter? All right, I will be serious; yes, I see your point. The classical curve does seem to go up and up. But isn't there a song, "What Goes Up Must Come Down?" (Your loved one starts humming the tune.)

You (exasperated): But how?

And the conversation would end there, in exasperated frustration.

The graph in Figure 3.1 is referred to as the *frequency distribution curve* of blackbody radiation. Why this particular name? Blackbody radiation is the light and other electro-

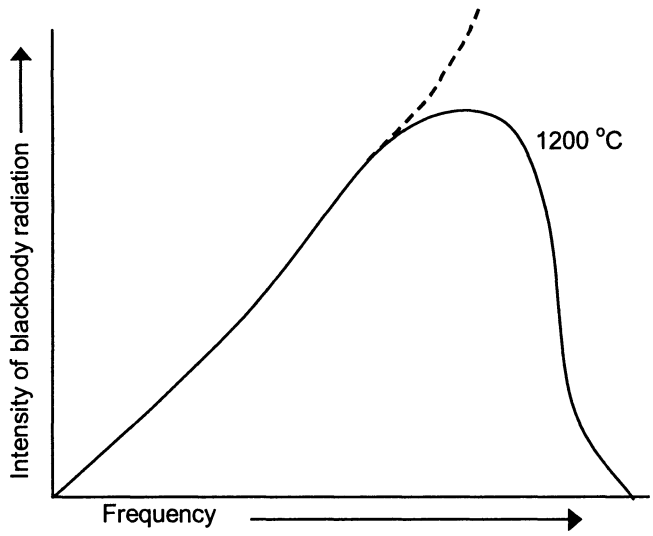

Figure 3.1
The spectrum of radiation emitted by an incandescent solid. The intensity rises to a maximum as the frequency increases and then tapers off at even higher frequencies. The dotted line shows the prediction of classical physics.

magnetic radiation that come out of a perfectly black enclosure, one that absorbs all the radiation that falls on it. When heated to a given temperature, the radiation of the blackbody theoretically can be shown to be dependent only on the temperature and on no other property of the body. It is thus an ideal source of radiation. The radiation spectrum of an incandescent solid is a close approximation to that of a blackbody. Figure 3.1 plots the intensity (energy from the blackbody falling per second and per unit area of an absorber) of radiation as a function of the frequency emitted.

The color (which is indicative of frequency) of the emitted light depends on the temperature of the substance. At low temperature the color is dull red (low frequency); then with increases in temperature the color changes to orange, yellow, white (signifying a mixture of the colors), and finally blue. The high frequencies begin to dominate as the temperature of the emitter increases. In fact, the peak of the distribution curve shifts to higher frequencies as the temperature increases (Figure 3.2), in accordance with what we see in the color. The peak frequency of maximum emission is indeed a signature of the temperature of the emitting body, and is used to quantitatively determine the temperatures of stars. As you may know, stars come in different colors depending on their temperatures: the coolest ones are dull red, and then we find orange stars, yellow (like our sun), white, and blue, in order of increasing hotness. (If you are wondering why we do not see stars in such vivid colors with our naked eyes, that has to do with the fact that only our color-insensitive rod cells of the retina are activated by the dim light of the stars.)

Question: Why don't we see any green stars?

Answer: Green, as you know, has a frequency right in the middle of the visible spectrum. So when green is prominent, so are the other frequencies on both sides, and the color would be white.

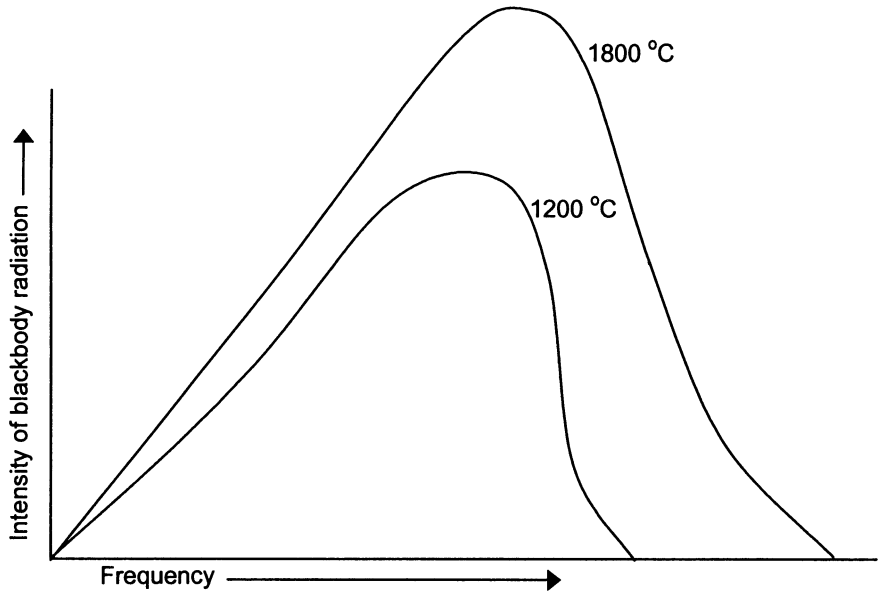

Figure 3.2
At a higher temperature the intensity is much greater than at a lower temperature. Also, the spectrum (and the maximum) shifts toward higher frequency at a higher temperature.

The classical physics model that people in Planck's time developed for blackbody radiation is based in part on *thermodynamics*, the science of interchange of heat and other forms of energy. There was also *Maxwell's electromagnetic theory*, another milestone of classical physics, to guide them. Maxwell's theory tells us that radiation must be due to the jiggling motion of a few charges among the atoms of the body. Ultimately, the charges can be identified as the electrons, but there are so many interactions that we can forget about the individual electrons and assume that the radiation is due to a few charged oscillators, ignoring the detailed character of the oscillators.

Now these oscillators move up and down and radiate and ordinarily lose energy and cool down. But if we keep them in a closed box with perfectly reflecting walls, the oscillators can keep on moving. They lose energy by radiation, no doubt, but some of the radiation comes back and returns the energy to the oscillator. Thus we can achieve a state of thermal equilibrium (no net one-way flow of energy) between the oscillators and the confined radiation. The average energy of such an oscillator is the same regardless of the wavelength of the radiation it emits; the average energy is just proportional to the absolute temperature. (*Absolute temperature* is temperature measured on the absolute temperature scale; if you add 273 to the Celsius temperature of an object, you get its absolute temperature.) All this is according to the classical physics known at the turn of the century.

Unfortunately, the number of oscillators of a given frequency increases rapidly with the frequency. And this means trouble. So one result of the classical thermodynamic theory above is that most of the energy inside the black box will be in the form of high-frequency radiation—ultraviolet and so forth. Of course, this is just not true if we review the experimental data of Figure 3.1. According to experiments, for any given temperature only a finite amount of energy is contained in the high-frequency portion of the spectrum. If the thermodynamic theory were correct, we would get sunburns from ultraviolet radiation every time we had a fire going in a fireplace.

What is more catastrophic is that in even a small part of the space inside the black enclosure, the total energy would be infinite, according to arguments as above, because of the contribution of the high-frequency oscillators to the total energy. So if the thermodynamic theory of radiation was the final truth, energy would just drain out of matter and go into radiation and everything would become absolutely cold. We all know that this does not happen. So what is wrong with this theory?

The Energy Quanta of Max Planck

Once in Soviet Russia a professor wrote down the equation

$$E = h\nu$$

and asked one of his students, "What is ν?" "Planck's constant," the student answered. Taken aback, the professor asked, "Then what is h?" "The length of the plank," the student answered unabashedly.

The student was slightly mistaken, as you no doubt suspect since in physics, the symbol ν almost always denotes frequency and it is not hard to figure out that E denotes energy. So the only unknown is h. But then, if you knew the name Planck, you would know of h; h is a fundamental constant of nature known as *Planck's constant*. The equation $E = h\nu$, introduced by Max Planck, was the first (but not the last) appearance of this constant h in our picture of the world. The entire quantum revolution can be traced to the potential power of this one mathematical equation.

What is so phenomenal about this equation? Before Planck's theory, energy had always been regarded as a continuous variable. Energy was assumed to be emitted or absorbed in as small a dosage as you can imagine, all the way down to zero. But Planck's equation says otherwise. For each frequency of the radiation emitted, the size of the energy bundle is h times the frequency: no more, no less. Energy can be exchanged from the system only in multiples of these bundles, or *quanta*. Energy is quantized. It is like having a minimum currency: we cannot exchange coins in any denomination less than a cent; all exchanges must occur in integer multiples of cents.

The constant h has the same units as the product of energy and time, or what physicists refer to as action. So h is often referred to as the quantum of action. The unit of h is the product of a unit of energy, which is a joule, and a unit of time, which is a second. Its value has been established from very careful experimentation to be

$$h = 6.62 \times 10^{-34} \text{ joule-second.}$$

As you can see, h is a very small number. This is the reason that the quantum nature of things does not play much of a role in the behavior of the macroworld, that is, in the motion of large objects.

Obviously, the classical theory needs some way to avoid the high-frequency catastrophe, some way to suppress the contribution to the total energy coming from the high-frequency components of the radiation spectrum. Since the number of oscillators increases rapidly with frequency, if the average energy of oscillators somehow decreased rapidly with frequency also, then the product of the two could be finite. This is what Planck was able to show with his $E = h\nu$. That, and the quantum jump.

Planck's sparkle of new insight into the problem was the realization that the charged oscillators of a blackbody can only absorb energy in quantum jumps, $h\nu$ at a time. The oscillators exist in states of quantized energy resembling a staircase: the steps of the staircase are called *energy levels* (Figure 3.3). This analogy is really a very good one. If you are walking on a ramp, your potential energy changes continuously, according to the classical assumption. But if you imagine yourself on a stair-case, your potential energy in earth's gravity field can change only by discrete steps, quantum jumps; the difference, of course, is that in everyday life we can build the staircase with steps of varying length. Nature, on the other hand, has a fixed length for its quantum jump, a length determined by h. This, in fact, is the significance of the quantum of action h.

So now we can imagine the following picture. For each frequency ν there are a lot of oscillators whose steps have the length $h\nu$. Many of them will be at the ground level, taking no energy at all. A few others will absorb one quantum of radiation and will move to the first excited state, but the number of these is much smaller than the number in their

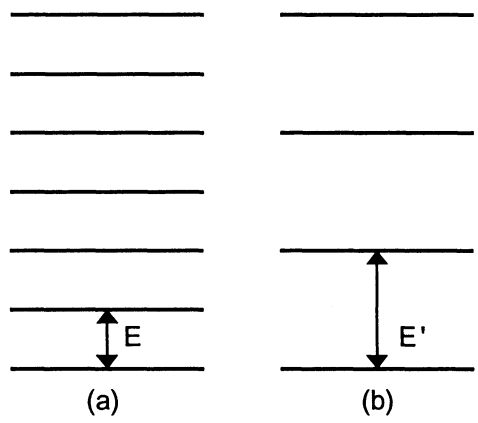

Figure 3.3
Planck's Energy Level Staircase of jiggling charges.
(a) The energy difference E between two steps is given by the famous formula $E=h\nu$, where ν, the frequency of the radiation, is the ratio of the speed of light and the wavelength.
(b) If the frequency is doubled (wavelength halved), the energy spacing of the steps of the staircase is also doubled.

ground states. And this is the way that the population of the higher levels of the staircase occurs; the population goes down exponentially for higher and higher steps of the staircase. Now we can find the average energy by summing up all the energy of these various oscillators on all the steps and then dividing that by the total number of oscillators of frequency ν. When we calculate this way, we find that the average energy is not just a multiple of the temperature, but now has an additional factor, which basically acts as the high-frequency cutoff that is needed to get agreement with experiment.

In India there is a legend about a mountain, the Bindhya, which divides North India from South India. In ancient times, it is said that this mountain was still in its growing phase, and it just continued to grow higher and higher, making transportation across the country very difficult. So the people asked a famous sage to solve the problem. Seeing the sage approach, the mountain bowed down to show reverence, as was customary (everyone in India must show reverence to a sage). The sage said to the mountain, "Stay like that until I return." The mountain agreed to obey, and of course, the sage never returned; he settled down in South India.

The magic with the quantum leap is similar. The radiation curve bowed in reverence to Max Planck, his idea of quantum leap was so great.

The radiation distribution law that Planck discovered following essentially this kind of reasoning (the details were somewhat different) is the famous *Planck's law*. The spectacular agreement of his law with the experimental data left no doubt in anybody's mind that the law was correct (Figure 3.4). Understandably, Planck's work did not have much immediate impact among his contemporaries. It was too revolutionary, too much against the grain of the prevailing belief system based on continuity. The idea that mass may exist in quanta of various sizes called the elementary particles was not in vogue yet, nor was the fact of quantization of charge (all charges observed in nature occur in multiples of the

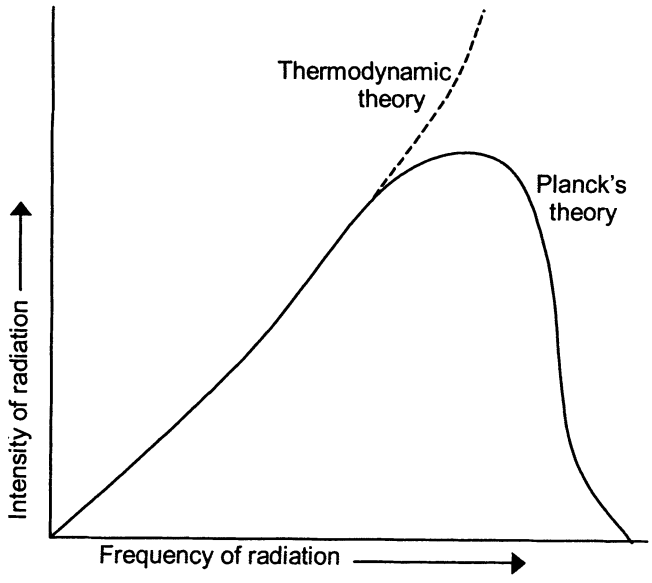

Figure 3.4
Planck's theory (the solid curve) agrees with the experimental curves in Figure 3.1 and Figure 3.2, but the thermodynamic theory fails dismally at high frequency.

charge contained in an electron) known for sure. We don't know if such knowledge would have made a difference, but it might have. Ironically, even Planck himself did not like the quantum jumps, so he spent a substantial portion of his later life trying to disprove his own work. Breaking with a belief with which you've grown up is not easy.

Yet, intuitively, Planck knew that his work was as important as Newton's in paving a new physics, as he privately confided to his son in 1901. Because of his own conservative beliefs, Planck felt stymied by the revolutionary nature of his own ideas, but these seminal ideas got other physicists excited, and eventually brought fruit. In truth, Planck was only underestimating the importance of his work, if anything. In retrospect, the importance of his work lies in the fact that it started a revolution in science—the quantum revolution—compared to which even the Copernican revolution pales.

Bibliography

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Tarcher/Putnam, 1995.

CHAPTER 4

Einstein's Photons

The development of the quantum ideas themselves occurred in discrete jumps, quantum leaps of the creative insights of a few people. The next significant progress came in 1905, five years after Planck had proposed the energy quanta, from a young man named Albert Einstein, who at the time worked in a patent office in Switzerland.

If one shines monochromatic light on a metal, electrons come out of it, but in a very odd way. The energy of the outcoming electron has nothing to do with the intensity of the wave train of radiation incident on the metal. Now this is not the way waves behave. You can imagine ocean waves imparting energy to a piece of driftwood on a beach. The more energy the waves have, the more energy they will impart to the wood; it is the total energy of the waves that counts. In contrast, if you fire a bunch of bullets at a piece of wood, one of which hits the wood, the energy all the bullets impart to the wood depends entirely on the energy of the bullet that hits it. The other bullets don't matter. If you shoot a large number of bullets, you increase your chance of hitting the wood, but the energy change of the wood upon being hit still depends on just the individual energy of the bullet that hits it. Thus, in the case of the interaction of a beam of light with a metal, the imparting of energy to the metallic electrons takes place as with bullets, not as with ocean waves. Indeed, having a more intense light beam just enhances the chance of the light "bullet" to hit an electron. More electrons are found to come out, but all with the same energy so long as you keep the frequency of the light fixed (Figure 4.1).

Einstein identified the individual bullets of light as energy quanta and eventually the name of *photon* was given to them; the phenomenon of ejection of electrons from a metal

A. Goswami, *The Physicists' View of Nature*
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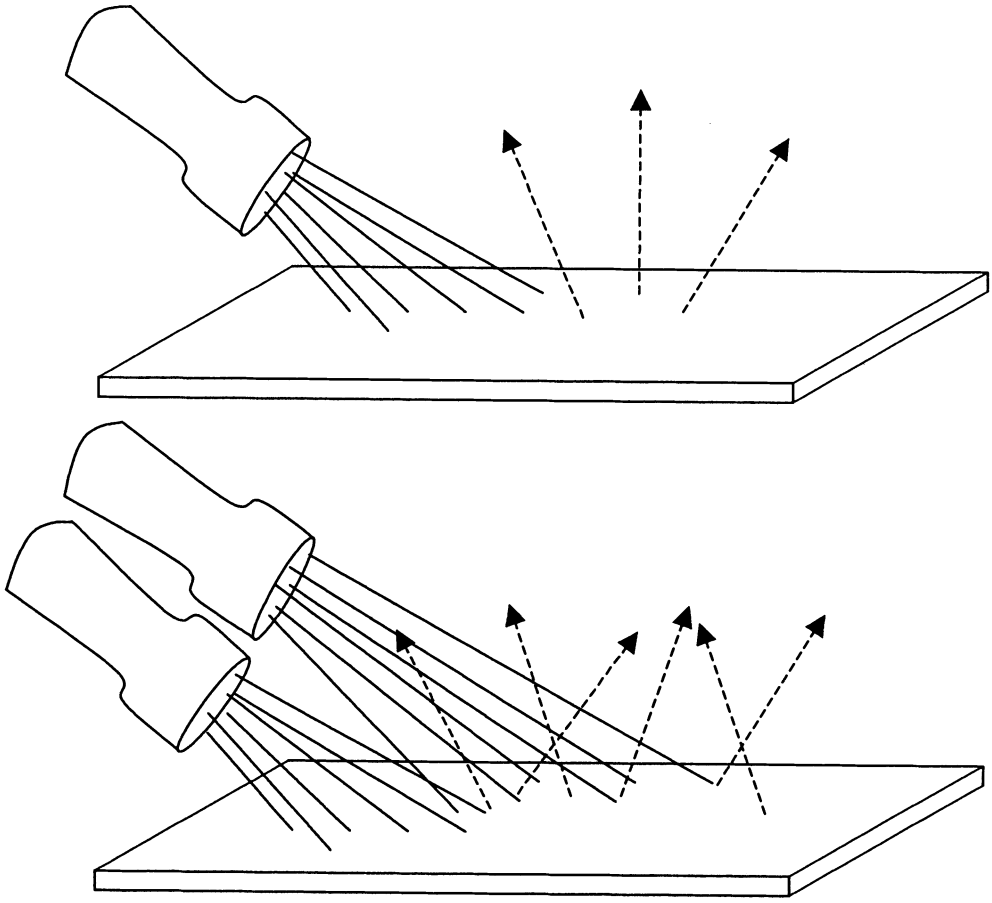

Figure 4.1
The number of photoelectrons emitted from a metal plate depends on the intensity of the light shone on the plate.

is called the *photoelectric effect.* For each photon, the energy is connected with the frequency through Planck's relation:

$$E = h\nu.$$

A high-frequency photon has more energy than a low-frequency one.

Figure 4.2 shows an experimental arrangement for observing the photoelectric effect. We let light shine on a negatively charged metal surface that then ejects electrons that are attracted to the positively charged plate, producing a current, as shown, which is measured by the current meter (called an ammeter).

Two interesting aspects of Einstein's photon theory of photoelectric effect are borne out by more elaborate experiments. First, for a higher frequency of the light beam, more energetic photons, we do get more energetic electrons. Second, and even more telling is

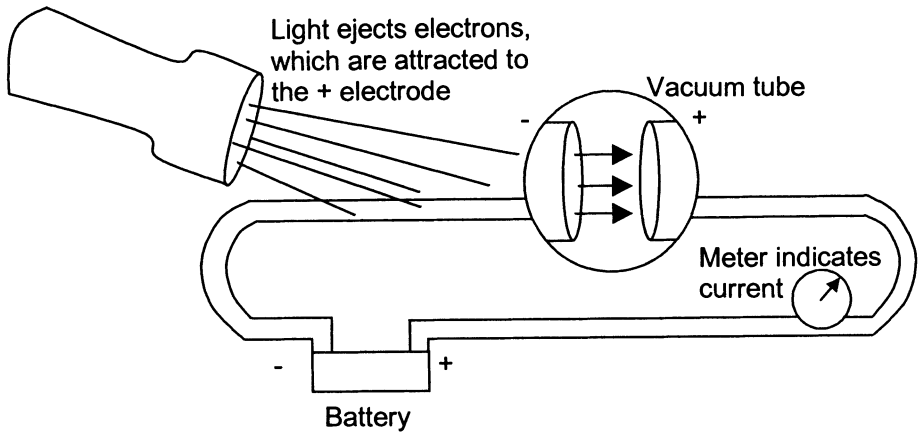

Figure 4.2
Schematic of an apparatus for measuring the photoelectric effect.

that often even an intense red beam is unable to eject photoelectrons from a metal, but even a weak blue beam carrying adequate individual photon energy does the job (Figure 4.3). You can relate to this. In a darkroom for developing film (which contains metallic compounds), red light is quite safe to use, but anything higher in frequency, even a little bit of white light, will ruin the film.

Thus, Einstein's work established the quantum nature of light. Let's consider an application of the quantum idea that you will like, it is within your everyday experience. There is something about vision in dim light that can be explained very simply by using the photon picture, but it is very difficult to understand if we insist that light is continuous energy. When we look at objects in dim light, we don't see sharp outlines; the shapes of the objects seem to merge into each other instead of being distinct. If the light energy coming to the receptors of our eyes were continuous, there would always be some light, albeit of low intensity, coming from all parts of an object and falling on all the receptors. Granted, the contrast between light and dark would not be very great in dim light, but this would not affect the sharpness of the outline.

Instead, what happens is that the receptors of our eyes work on the principle of photoelectricity—they respond to the graininess of light, to the individual photons. Since dim light gives fewer photons, this means that too few receptors will be stimulated at one time to define an outline or shape of the object; the picture is too fragmentary. If the receptors stored the information, of course, there would be enough fragmentary pictures for the brain to put together to make the whole. Unfortunately, the receptor information is retained for only a tiny interval of time, so the result is that in dim light not enough receptors will fire at any one time to give a sharp picture of the shape of an object. Next time you say goodbye to your loved one in twilight, watch how, as he or she moves away, his or her silhouette becomes more and more obscure, and then you can think of photons; surely that will lessen the pain of separation. The opposite effect of this happens when we develop a photographic film. Initially we cannot see a distinct shape; the image is too fragmented. Only when there are a lot of grains of the film developed is there a shape.

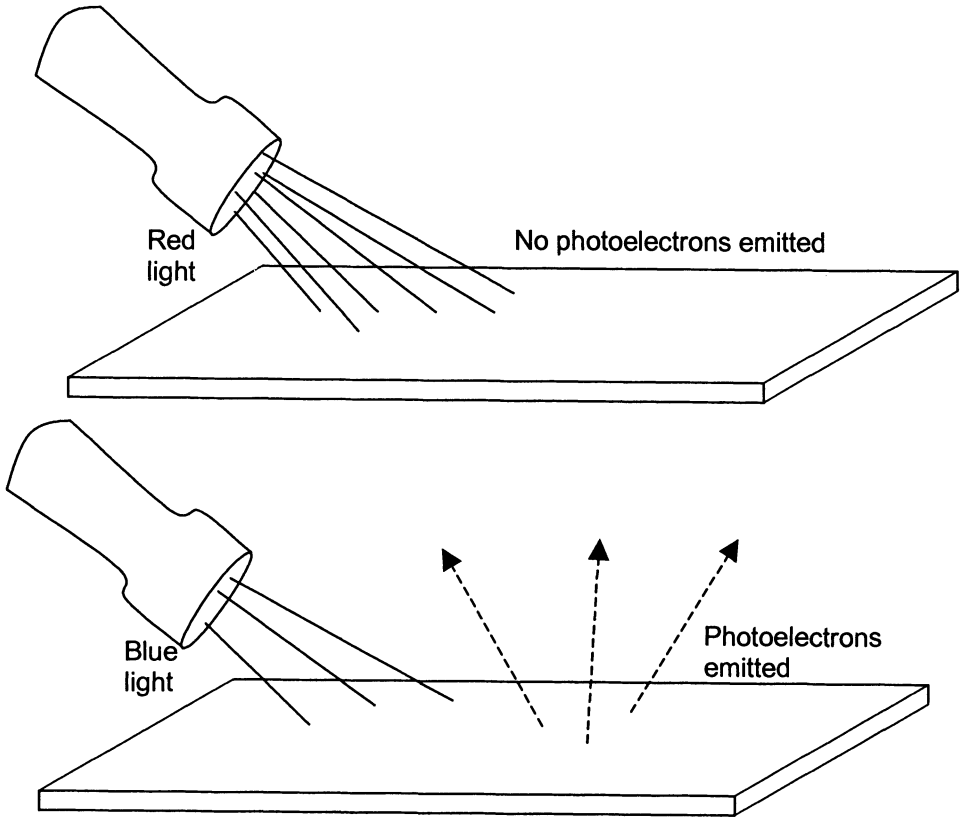

Figure 4.3
Even intense red light does not cause photoelectrons to be emitted from the metal plate; even weak blue light does cause photoelectrons to be emitted.

Question: If a beam of blue photons has the same total energy as a beam of red photons, which beam has more photons?

Answer: The red beam, of course. Because the energy per photon is lot less for red than for blue, the red beam has to make up by number.

Wave-Particle Duality of Light

If light consists of quanta, bundles of concentrated energy, then is light better conceived as particles than waves? The problem is that light also behaves like waves, and it is quite easy to verify that this is so. Just go out on a dark night with an umbrella and look at a distant street light through the fabric of the umbrella. If light were particles, the pattern you should expect is the same as when sugar falls through a sieve, making a lump below. But when light falls through an umbrella into your eyes, there is not one lump, but an entire pattern of fringes greets your eyes. This is to be understood as diffraction of light—light waves bending around the fabric. (You must be familiar with the phenomenon

of diffraction of sound—bending of sound waves around a corner—as when you can hear your friend speaking from behind a wall. Diffraction of light is the same phenomenon, unmistakably telling us of light's wave nature.)

So how can light be both wave and particle? When you think about it, this should be very surprising. Particles are localized entities, always following definite trajectories of movement. In contrast, waves spread out, they have the ability of being in two or more places at the same time. Verify this. Throw a ball and see that it describes a trajectory, always being at one place at a time. Now speak and see that more than one person can simultaneously hear your every word, giving away the secret that waves can reach more than one place at the same time.

So Einstein's discovery of the particle nature of light in addition to the earlier-known wave nature makes one thing very clear. The quantum dimension of reality is weird, very contrary to our common-sense expectation. Of course, there is a little consolation in the wave-particle paradox—light shows up as particle in some experiments (e.g., the photoelectric effect), and as waves in some other experiments (for example, diffraction experiments), but never as both wave and particle in the same experiment. Later, we will see that this was the Danish physicist Niels Bohr's basis for understanding the wave-particle duality as complementarity—the wave nature and the particle nature of a quantum object are complementary aspects.

Actually, Niels Bohr is famous not so much for his attempt to understand the wave-particle duality, but for a model of the atom he built, a model that paved the way for quantum physics, a full-fledged replacement of Newtonian physics. We now turn to a discussion of the Bohr atom.

CHAPTER 5

The Bohr Atom

Somebody once said about the Greek language that Greek flies in the writings of Homer. The quantum idea started flying with the work of Danish physicist Niels Bohr published in the year 1913.

Scientists have an advantage in their creative work—they get to look at nature from the vantage point atop the "shoulders of giants." Besides Planck and Einstein, Niels Bohr had access to the shoulders of another giant, Lord Rutherford of Nelson, who dominated British physics in the first few decades of the 20th century. Bohr was a postdoctoral research associate who came from Denmark to work with Rutherford.

Rutherford had a model of the atom, established in part from experimental observations, that intrigued Bohr no end. In this model the atoms consisted of electrons moving around nuclei; electrons were light objects that went around a central massive nucleus.

Almost all the mass of the atom resides in the nucleus; this was proven experimentally by Rutherford in an ingenious experiment. Before Rutherford, the English physicist J. J. Thompson, who discovered the electron back in 1887, had a model of the atom that proposed that atoms are like lumps of positive electric charge in which are immersed the negatively charged electron (so the overall atom is electrically neutral), very similar to little plums in a pudding. But when Rutherford hit the atoms of a gold foil with high-energy alpha particles of positive charge like a target shooter hits a target with bullets, he found no evidence at all in favor of the plum-pudding model. Most of the time the alpha particles just passed through the atoms undisturbed, suggesting that most of the atom is empty space. Most strangely, there were a few alphas that were deflected at very sharp angles, even coming back out where they entered.

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Such large angle scattering (Figure 5.1), said Rutherford, can be explained only if the positive charge of the atom resides in a very tiny central core, the nucleus, which contains most of the mass of the atom. The positively charged alpha particles were being strongly repelled by the positively charged nucleus whenever they came close; hence the large angle scattering. And Rutherford backed up his argument with mathematics.

Since the electrons are drawn to the nucleus with an attractive electrical force following the inverse square law (the force decreases inversely as the square of the distance), it is very tempting to make a tiny solar system model of the atom, in which the electrons revolve around the nucleus like planets do around the sun, under the inverse square law of gravity. If the electrons moved with just the right range of velocities in their orbits, the electrical force has the right magnitude to make them go around. So this works out. The problem is this: an orbiting electron is an accelerated one because, in the least, the velocity keeps changing directions. According to Maxwell's theory of electromagnetism, a previously mentioned milestone of classical physics, an accelerated charge must radiate. Even that is all right—atoms do radiate light. But now as the electrons radiate, they must lose energy and spiral inward toward the nucleus. Eventually this leads to a collapse of the atom. This is similar to the collapse of our artificial satellites that go around the earth but lose energy to air friction so that their orbits decay.

So Rutherford's atom is not stable (Figure 5.2). Niels Bohr made it stable by injecting the quantum idea. Just as in the case of the quantum oscillator of Planck, the electrons of an atom must also exist only in quantized energy levels, or stationary orbits, because the orbits don't decay. The electron's orbits are quantized, discrete (Figure 5.3), said Bohr. Most importantly, Bohr realized that an electron does not radiate when in one of these stationary states, but only when it takes a jump from a higher to a lower energy level. The difference of energy between the levels involved in the transition comes out as light (or other electromagnetic waves). If the electron is in the lowest (ground) energy level, its ground state, then the atom is stable because the electron has no other lower energy level

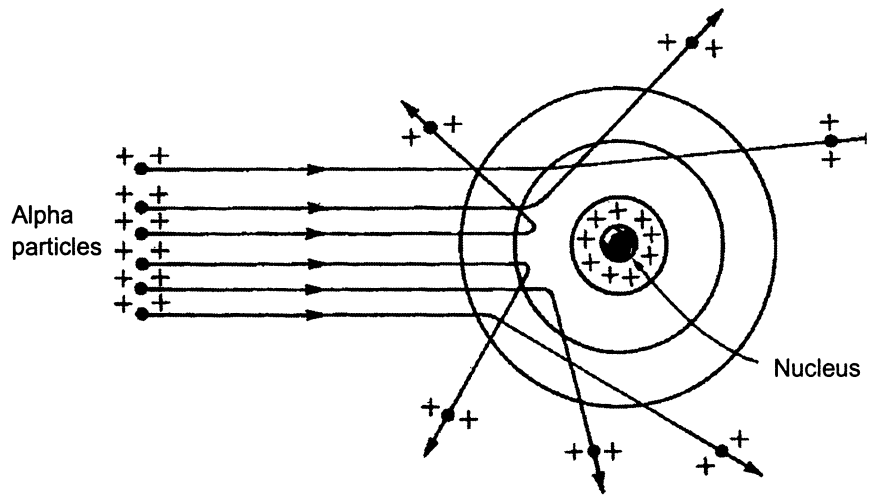

Figure 5.1
Rutherford's scattering experiment. Some of the alpha particles are turned backward by the repulsion of the heavy nuclear core of the gold target atoms.

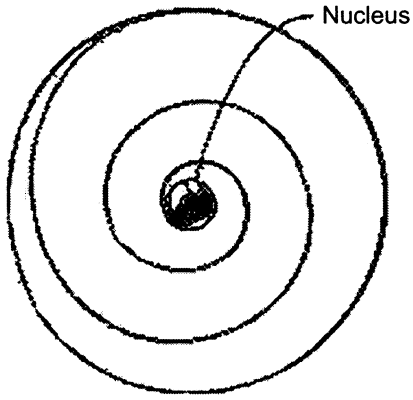

Figure 5.2
In Rutherford's original model of electrons going around a central nucleus, the electrons are destined to lose energy by radiation, and they will spiral inward, eventually falling into the nucleus.

to jump to. In this way the atom gains stability. An atom with all its electrons in their respective lowest permissible orbits is stable; there is no chance for any of the electrons to crash into the nucleus, declared Bohr, and physicists everywhere on earth greeted his discovery with a great sigh of relief. Look at a modern picture of the electron orbits of a stable gold atom based on the original idea of Bohr (Figure 5.4); doesn't it look like a Tibetan mandala? Indeed, Bohr's atom became the new mandala for physicists to meditate upon for quite a while.

But how does one describe the motion of an electron when in a stationary state, or while it is making a transition from one level to another? The stationary orbit is not like a planetary orbit, contrary to what you may think, and Niels Bohr was quite aware of this. This is why he carefully called the electronic states in the atom "stationary." An object in a classical orbit is not stationary; it changes with time. In contrast, for a stationary state nothing changes with time in any way that lends to a classical description, and Bohr was clear on that. I hope that now you are too.

Thus, if you ask questions like, "What does the electron do when in one of these stationary states?" you are wasting your time. We don't know. Maybe it improvises; maybe it is granted a certain amount of freedom of improvisation like somebody performing

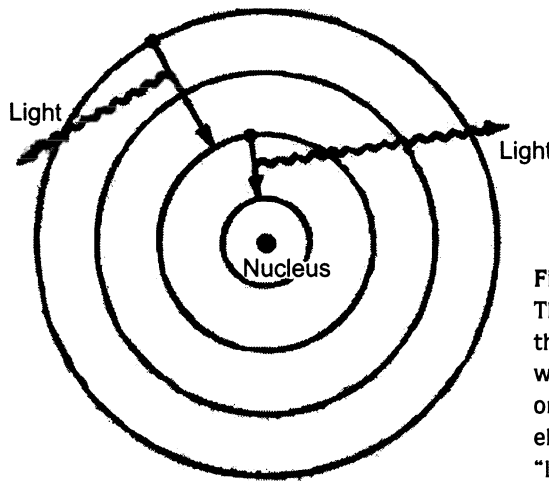

Figure 5.3
The electronic orbits of the Bohr atom. In this model, the electrons do not radiate while they are in one of these "stationary orbits." Radiation occurs only when an electron jumps from a "higher orbit" to a "lower" one, as shown.

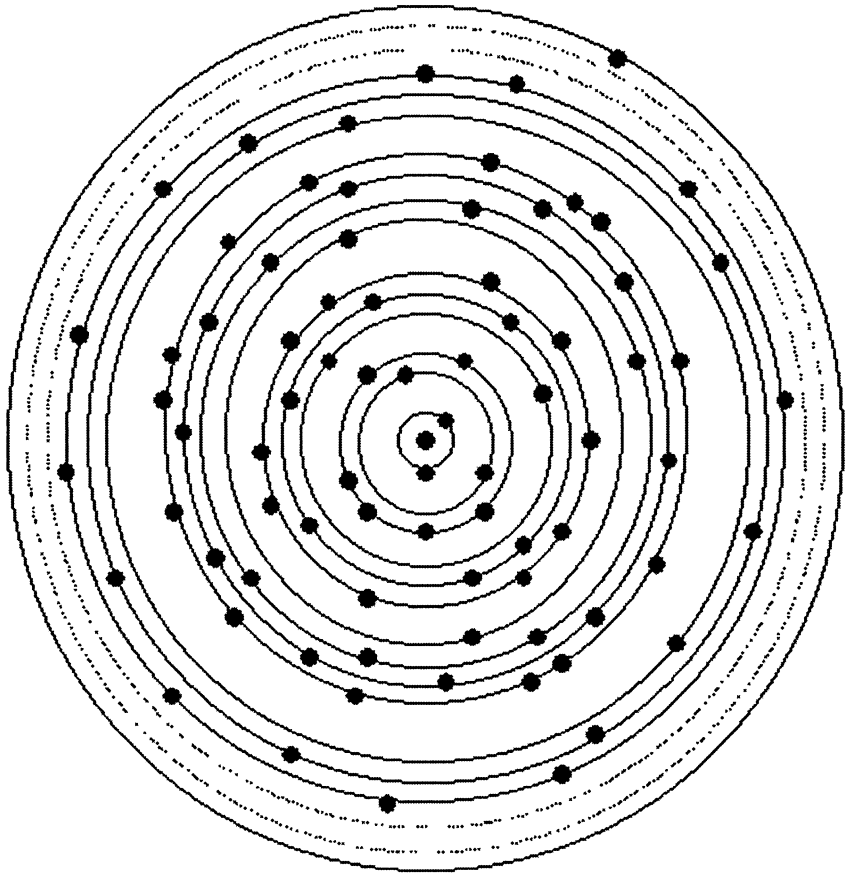

Figure 5.4
A modern picture of the electron orbits of a stable gold atom.

jazz music. Actually, we don't even much care to describe the electron while it is in one of these stationary states, because the electron doesn't do anything that is observable while in these states. So we allow ourselves to be a little ignorant (which a classical physicist abhors) because, as we will see later, the ignorance is imposed on us by nature. The situation is best described by the following quotation from *Science and the Common Understanding*, by American physicist Robert Oppenheimer:

> If we ask, for instance, whether the position of the electron remains the same, we must say 'no'; if we ask whether the position of the electron changes with time, we must say 'no'; if we ask whether the electron is at rest, we must say 'no'; if we ask whether it is in motion, we must say 'no.'

Likewise, when an electron takes a jump from one orbit to another, can we describe that jump in space-time? No. The electron never goes through the intervening space between orbits taking the usual time. The quantum jump is truly a discontinuous affair. Now the electron is here, and then it's there.

What is happening today is that we may be at the brink of verifying the discontinuous quantum leap of the electron in quantum phenomena. There is a phenomenon called *electron tunneling*: the electrons in transistors, for example, go across energy barriers. Do they tunnel through, as the name of the phenomenon suggests (no doubt due to the classical prejudice of the experimentalists who discovered the phenomenon), or do they leap across Bohr style, never going through the intervening space? Unfortunately, we cannot look at what is happening inside the barrier without destroying it; thus, until now, this has been a difficult matter to settle.

These days, though, very accurate time measurement enables us to measure the time taken by the electron for going across an energy barrier, and this time is found to be so small that the speed of the electron while crossing the energy barrier is inferred to be faster than that of light. But Einstein proved long ago as part of his theory of relativity that no material object can travel faster than the speed of light; the speed of light is the absolute speed limit in nature's highways (an idea that has also been verified by experimental data). So Bohr is right with his idea of the discontinuous quantum leap, the electrons in the tunneling phenomenon never go through the space of the energy barrier, they transcend it. Caution: this conclusion is still a little controversial.

Atoms and Philosophy

I hope you see the gaping opportunity that the idea of discontinuous quantum leaps creates to question some of the philosophical prejudices of classical physics. There are two kinds of motion in the world: *continuous motion*, as when the electron is describing a stationary orbit, and *discontinuous motion*, as when the electron takes a quantum leap from one orbit to another. During the first kind of motion, continuous motion, classical ideas such as causal continuity and determinism hold. But discontinuity is the harbinger of new ideas; it can be seen as a window through which consciousness and free will can enter physics and the physical world.

The point is this. Discontinuity means a breakdown of causal continuity. We cannot give a precise cause as to when the electron is going to make a jump. Or if there is more than one orbit or energy level to jump to (Figure 5.5), we cannot say precisely which orbit the electron is going to leap to or when. The electron's quantum leaping is acausal. So is it an act of free will of the electron?

In the beginning, Bohr and others did ponder such questions as, "Does the electron have free will?" But as the new physics took more accurate shape, it became clear that to ascribe to the electron free will is too simplistic; instead we have to bring ourselves into

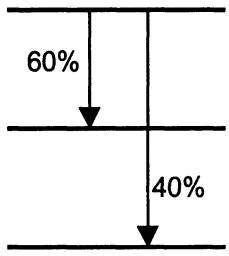

Figure 5.5
The observer does not know to which orbit the electron will jump, or when.

the picture, the subjects, or observers. The discontinuity in the movement of the electron, when properly viewed from the vantage point of later-discovered mathematics of the new physics, suggests no less than a discontinuity in our ***knowledge*** about the electron. In that discontinuity, there is room for consciousness, because how do we gain knowledge except through our consciousness? So the question is not of electrons' having free will, but a much more important one of our having free will. We may not be the determined machines that Newtonian worldview holds us to!

Question: If causality breaks down for the quantum-leaping electrons in atoms, then how can we do physics?

Answer: We have to introduce statistical ideas such as probability. We have to learn to talk about the average behavior of the electrons. In Figure 5.5, where is the electron going to leap to? We can say that the probability of leaping is maybe 60% to the first "excited orbit," and 40% to the ground orbit. Also, one electron jumps now, another electron later. If we average over all these times, an average lifetime of the electronic state in the orbit can be defined.

Bibliography

Oppenheimer, R. *Science and the Common Understanding*, p. 69. NY: Simon & Schuster, 1954.

CHAPTER 6

The Discovery of Quantum Mechanics

A prince of the de Broglie family in France had a very clever idea for his doctoral thesis in physics. The prince, named Louis de Broglie, was familiar with the stationary states of the Bohr atom, and they reminded him of the stationary or standing waves of musical instruments (with which you also may be familiar; watch a guitar string while it is making music, you will see the particles of the string waving while standing in place). One of the most intriguing aspects of the stationary waves on a guitar string is the discrete nature of the allowed frequencies that can be set up. For a given length and tension of the wire, the music of the guitar string displays the same kind of discontinuity that is characteristic of the electronic energy levels of an atom. But if there is a connection, the electron has to be a wave, and the atomic electrons must be confined waves. *Traveling waves* propagate (Figure 6.1), but confined waves do their waving in place, forming standing or *stationary waves* (Figure 6.2).

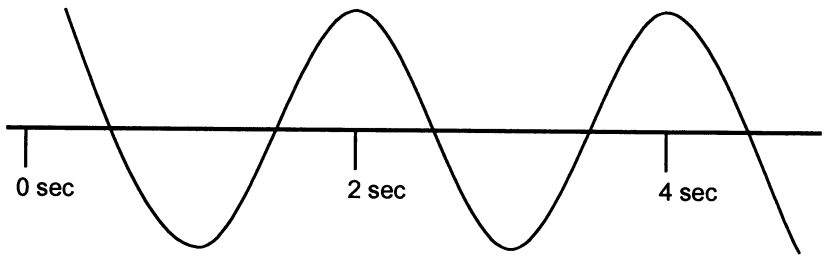

Figure 6.1
Traveling waves propagate.

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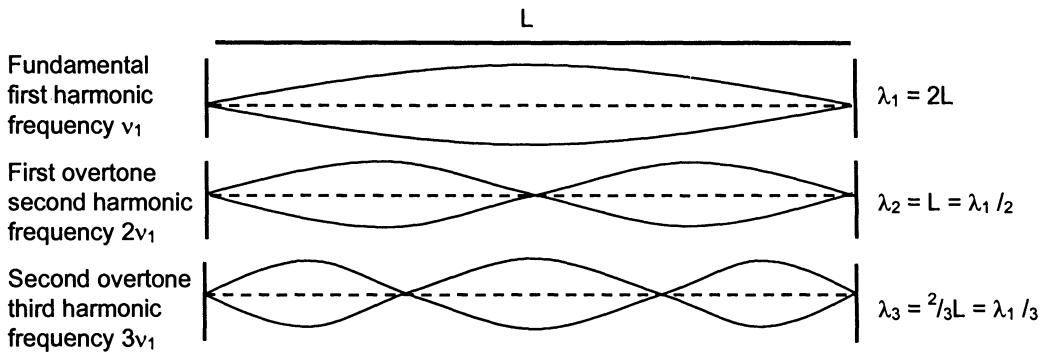

Figure 6.2
Confined waves do their waving in place, forming standing or stationary waves; for example, at the top of this figure, the disturbance is shown at each point, it rises to a maximum, goes to zero, arrives at a negative maximum, goes back to zero, and repeats.

The stationary states of the electron in the Bohr atom could now be pictured in the following way. The electron is no longer a localized particle moving in an orbit. Instead, it behaves as a stationary wave that surrounds the nucleus of the atom. The lowest stationary state is one in which one electron wavelength fits the circumference of the Bohr orbit. Excited atomic states of the electron correspond to fitting two or more (but always an integral number of) wavelengths within the circumference of the Bohr orbit. (Figure 6.3).

The quantum picture of the atom that now emerges is remarkable. It explains in simple terms three important properties of the atoms, namely, their stability, their iden-

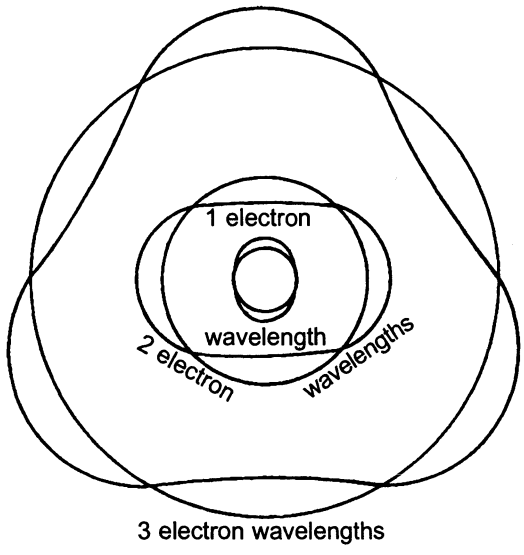

Figure 6.3
Stationary waves of electrons in the confinement of an atom. The electron wave fits an integral number of wavelengths in each of the successive Bohr orbits.

tity with one another, and their ability to regenerate themselves. Their stability derives from the fact that it takes a fairly large amount of energy to lift an atom from its lowest stationary state (the ground state) to another. This was already pointed out by Niels Bohr.

With de Broglie's electron wave idea, we can understand the identity of atoms as the result of the identity of wave patterns in confinement: the stationary pattern is determined by the way the electrons are confined, not by the properties of their environment. Thus, an atom of hydrogen on earth must be identical to one found on the sun. Just like a guitar's music, the music of the atom is the same, wherever you find it.

Also, once the atom is recognized as a vibrating system, it becomes clear why it has the remarkable property of returning to its previous state after it has undergone a period of distortion and excitement. The stationary patterns depend only on the conditions of the confinement in which the electron executes its motion; the pattern has no recollection of the past history.

Wave-Particle Duality of Matter

A most important aspect of the de Broglie way of looking at the electron, which everybody knows is also a particle (as when we measure it with a Geiger counter as a localized tick of the counter), is that it imparts to the electron the same duality that light has. The electron is a wave as well as a particle. And not only light and electrons, but all matter has this duality, if we make an obvious generalization. This was recognized by de Broglie as a consequence of Einstein's work: that mass of matter and energy are the same. It seemed right to him to attribute physical properties to matter and light in a symmetric fashion.

De Broglie also postulated that the wavelength of the wave associated with a particle is related to the momentum of a particle. If p is the momentum of a particle, the de Broglie wavelength λ of its wave is given as

$$\lambda = h / p.$$

The story is that de Broglie had a hard time getting his Ph.D. thesis approved. Eventually his thesis was sent to Einstein for appraisal. Now Einstein, who originated the duality idea for light, had no difficulty in seeing that de Broglie was right. Matter is also dual. Furthermore, Einstein himself had put a big hole in the integrity of the concept of matter by showing that mass and energy are the same thing. Now de Broglie's work carried the same theme a little further by showing that matter had wave properties too. So Einstein wrote back about the thesis something to the effect that it might look crazy, but it really was sound. After that, de Broglie was given his degree.

Experimental Observation of Matter Waves

Let's discuss the experimental evidence for matter waves. The evidence lies in the observation of diffraction (bending around obstacles or slits) or interference (when two waves meet, their disturbances superpose or interfere to produce the total effect) patterns

due to matter waves. Since an electron wave has a wavelength of atomic dimensions, 10^{-10} meter, to see diffraction we must find slits as small as atoms. Fortunately, nature provides us with such slits in the form of crystals. Crystals are regular three-dimensional arrangements of atoms; the distances between the atoms are just the right size. In fact, this was determined by looking at diffraction patterns that X-rays produce when passing through a crystal. American physicist Clinton Davisson was the first to discover that a beam of electrons passing through a crystal gives a pattern similar to that of X-rays—conclusive proof of the wave nature of an electron (Figure 6.4).

Since the days of Davisson, literally thousands of different experiments have shown the wave nature of matter on a submicroscopic scale.

Wave Property of Macroscopic Matter

De Broglie's formula for the wavelength of matter waves also makes it clear that for macroscopic matter the wave properties are suppressed because the wavelength turns out to be extremely small. For example, if the mass of a bullet is 2 grams, or 2×10^{-3} kilogram, and the velocity can be taken to be 300 meters/second, then

$$\lambda = \frac{h}{mv} = \frac{6.62 \times 10^{-34}}{2 \times 10^{-3} \times 300} \approx 10^{-33} \text{ meter.}$$

This is really, really small, and nature does not give us any holes or obstacles of this size to experiment with the wave nature of macroscopic matter waves propagating in space. So we are never going to encounter interference or diffraction with macroscopic matter waves propagating in space.

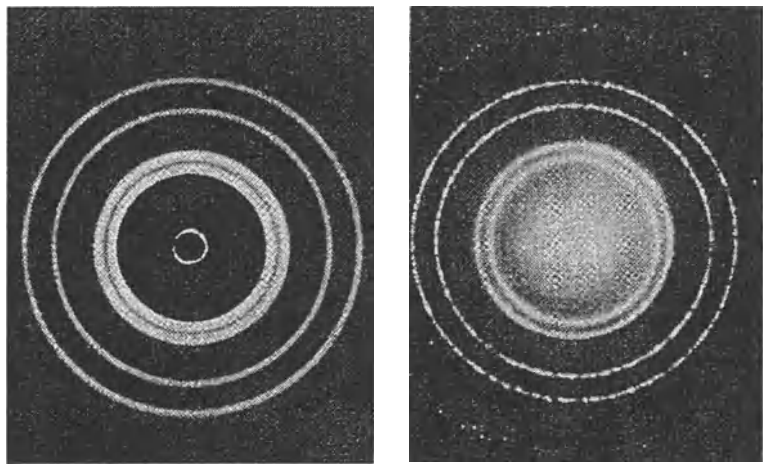

Figure 6.4
Diffraction pattern produced by electrons when passed through an aluminum foil (left) is qualitatively the same as that produced by X-rays on aluminum (right). (Courtesy J.T. Shipman.)

Heisenberg's Discovery

One of Niels Bohr's great contributions to human knowledge was to spread the word that there was a new mechanics to be discovered, a new way of looking at things based on the quantum principle. Many talented young scientists were impressed by his mission and gathered around him, forming the Copenhagen School for the study of the atom. And one of them, German physicist Werner Heisenberg, was the first to discover the equations of the new mechanics that were to replace Newton's mechanics in the microdomain of nature. Heisenberg wrote about his discussions with Bohr:

> I remember discussions with Bohr which went through many hours till very late at night and ended almost in despair and when at the end of the discussion I went alone for a walk in the neighboring park I repeated to myself again and again the question: "Can nature possibly be as absurd as it seemed to us in these atomic experiments?"

The answer to that question for Heisenberg was clearly a resounding "yes," judging from his subsequent work.

Heisenberg discovered that quantities like position and momentum of an electron are rather peculiar; the order in which we measure them matters. In other words, the product of two quantities a and b in quantum physics depends on the order in which you multiply them, $ab \neq ba$; the commutative law of algebra that we routinely assume for physical quantities in classical physics does not hold. It's a little like something that all romantics know: the order in which you ask "Do you love me?" and "Do you like me?" matters.

Heisenberg developed a whole new mechanics of matter based on this non-commuting algebra. However, the significance of the new quantum mechanics of non-commuting quantities becomes clearer in a different formulation based on the idea of matter waves.

The Schrödinger Equation

If there are waves, then there should be a wave equation, a mathematical equation that determines the waves completely for any given situation—so said a physicist to an Austrian physicist named Erwin Schrödinger. The physicist who made the comment promptly forgot about it. But the comment made an impression on Schrödinger, who went ahead and discovered the wave equation for the de Broglie waves. He applied the equation to the case of the motion of the electron in the hydrogen atom and found that it worked. All the quantum properties of the electronic motion that Niels Bohr had postulated now came out as a solution of the *Schrödinger equation* (the name given to Schrödinger's wave equation). There is, of course, some added subtlety. For example, Niels Bohr's concept of stationary orbits is formally replaced by the concept of stationary energy states or energy levels (Figure 6.5).

Soon Schrödinger was able to prove that his theory was identical to the one developed earlier by Heisenberg: his and Heisenberg's theories are two representations or

pictures of the same thing. There is only one mechanics, which is now called quantum mechanics. The calculations of this mechanics are more easily done using the Schrödinger picture, so we almost always solve a Schrödinger equation to find the motion of submicroscopic objects. And the agreement with experiment is always excellent, at least when the objects are nonrelativistic (i.e., move with velocities less than $0.1c$, c being the speed of light). For relativistic situations, the Schrödinger equation has been suitably generalized and then it works for "all of chemistry and most of physics." Thus, in the microdomain, the new quantum mechanics has completely replaced the Newtonian framework for calculating the motion of objects.

Question: If quantum mechanics is a mechanics as the name suggests, the mathematical theory of machines, then are you saying that all the weirdness that we spoke about earlier will now find answers?

Answer: Hardly. Calling quantum mechanics a mechanics was a shortsighted mistake that occurred because Schrödinger and others originally thought that with the advent of the mathematics of the movement of matter waves quantum weirdness would disappear and continuity would reign over physics once more. But this did not happen. Quantum mathematics does not give complete answers as to the motion of the objects it governs, but only points to what possible movement may occur (see next chapter). In this incompleteness, weirdness returns again.

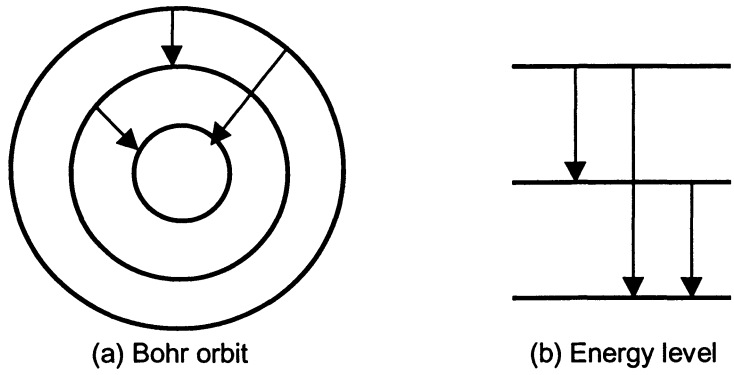

Figure 6.5
(a) Inaccurate depiction of electrons' movements.
(b) Accurate depiction of electrons' movements.

Bibliography

March, R. *Physics for Poets*. NY: McGraw Hill, 1978.

CHAPTER 7

Possibility Waves, Uncertainty, and Complementarity

What kind of waves are matter waves? When is an electron a wave and when is it a particle? Particles are localized concentrated objects with clearly defined tracks, whereas waves spread through large distances and can be in various places and volumes of space at once. These are very different properties. Can the same object have such diverse properties?

Clearly, we are in a tight situation. We are trying to describe what is in a new domain of nature with images developed for another domain. Logic in the familiar form is of limited use here. So we will use imagination, a gedanken experiment to get an understanding of this strange affair. Some of the most startling aspects of the dual picture will emerge from our analysis.

The gedanken experiment that we choose is called the ***double-slit experiment***, a well-known experiment that was originally used by English physicist Thomas Young to demonstrate the wave nature of light. This time we use the setup (Figure 7.1) with an electron beam; since both light and electrons have dual properties, the results turn out the same for both.

In this experiment, the electrons from a source go through a double-slitted screen before falling onto a fluorescent plate or a photographic film. The electron wave passing through the two slits splits, becoming two waves. The two waves now interfere at the screen, producing a pattern of alternate dark and bright fringes called the interference pattern.

How does the interference pattern happen? The first thing you notice is that the waves

A. Goswami, *The Physicists' View of Nature*
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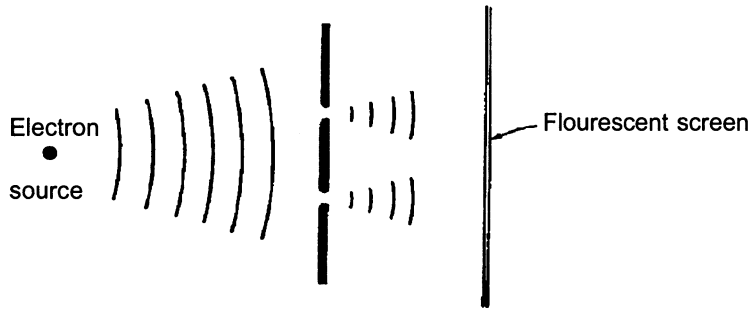

Figure 7.1
A double-slit experiment with an electron source.

are travelling different distances to the various points of the screen (except one), and so their phase difference varies from point to point. If crest and crest arrive together at a point on the fluorescent screen, the waves add and we get reinforcement; this is called *constructive interference* (Figure 7.2(a)). These are the places where the resultant wave is strong, and we get bright fringes there.

If, on the other hand, crest and trough of the two interfering waves arrive together at a place, they add *destructively* (Figure 7.2(b)) and give us dark spots on the fluorescent screen. The interference pattern is one of alternate bright and dark fringes (Figure 7.3),

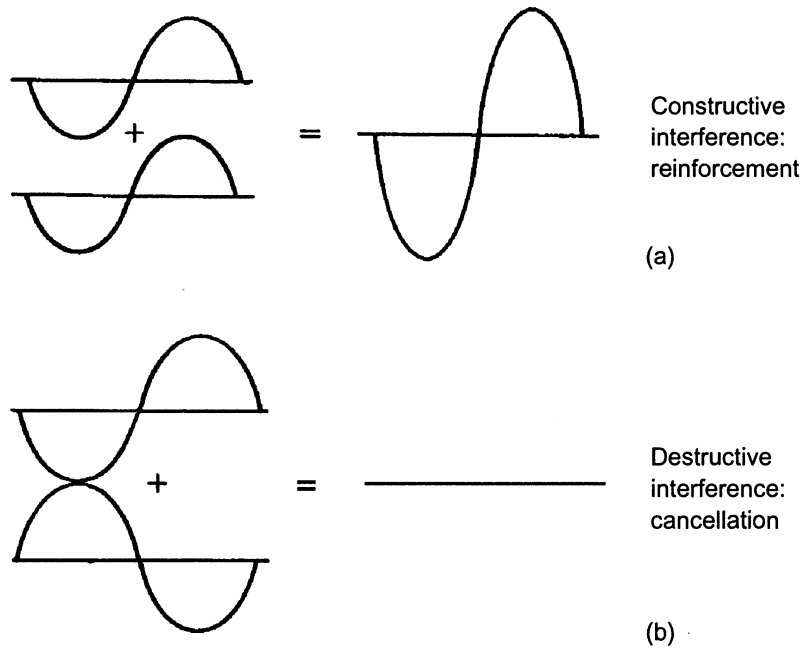

Figure 7.2
Interference.
(a) Waves in phase interfere constructively.
(b) Waves out of phase interfere destructively and cancel each other out.

exactly similar to the case of interference of light. With the help of a little mathematics, we can even determine the wavelength of the electron waves from the spacing of the interference fringes.

Are electrons waves then, like light? Some physicist of the old days argued that the wave property of the electron is an ensemble-property, a property that arises only when there are many electrons as in an ensemble. You might have a similar reservation—how can a single electron split and interfere with itself? But you can maintain your skepticism only so long. Suppose we make the electron source very weak, so weak, in fact, that at any one time only one electron arrives at the slits. Will we still see the interference pattern? Since the dual property extends to individual electrons, our answer must be yes.

But now we are back to the paradoxical question: "How can a single electron split? Aren't electrons supposed to have integrity?" Without a split beam or two waves, we cannot imagine interference. On the other hand, it is equally impossible to imagine that an electron, a particle, can literally split and pass through two slits at the same time.

Does the electron split? We can attempt to find out by looking. We can imagine a strong light beam that illuminates the electrons so we can see at any given time which hole an electron is passing through. Or is it passing through both holes, or what? So we turn the light on, and as we see an electron pass through a slit, we also look to see where the flash appears on the fluorescent screen. Every time an electron goes through a slit, we find that the flash appears behind the slit it just passed through. So after a time the electrons will make a pattern like Figure 7.4; the interference has disappeared.

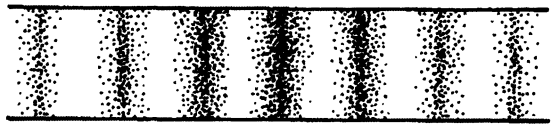

Figure 7.3
Interference pattern from a double-slit experiment.

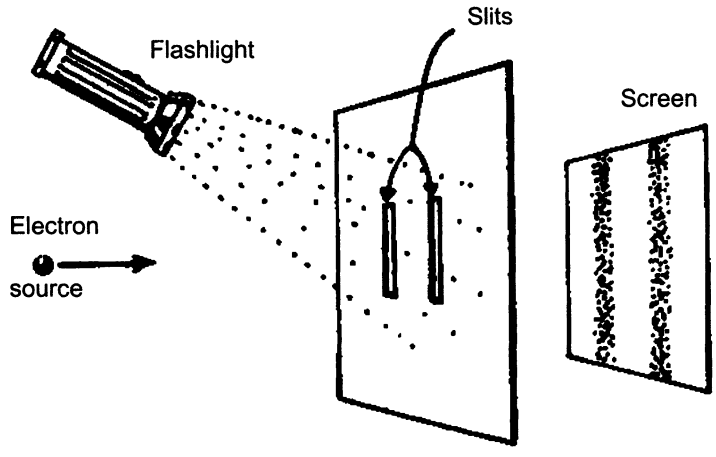

Figure 7.4
If we keep track of which slit the electrons pass through, we get the pattern on the screen shown here. The interference pattern has disappeared; the electrons behave as particles.

So now we have answered our first question. When we observe with a flashlight, the electrons pass through only one hole at a time; they don't split. By our looking, we must be encouraging the electrons to behave as localized particles, and a particle does not split. But when we don't observe, the electrons pass through both slits, and behave as waves. How so? Because they are waves of *possibility*.

You can easily get yourself upset by thinking that an electron always passes through one of the slits (since that's what we find when we look for it), and yet when we are not looking, the presence of the other slit affects the outcome of the experiment so that we get an interference pattern. However, you can't quarrel with what is. The experimentally established dual nature of the electron tells us that if we have a setup for detecting wave interference for the electron, we will observe such a pattern as long as we make no attempt to observe which slit the electron is passing through. We can interpret this. It means that the relation of the electron wave to the finding of the particle at a specific spot on the screen is a probabilistic one. Where the wave is strong, we can expect that the electron is likely to be there. Wherever the wave is weak, the electron is unlikely to be found. The density of spots on the screen corresponds to the probability of finding the electron. This *probability interpretation* is due to German physicist Max Born. The electron waves are probability waves or better yet, *possibility waves* because it is clear that the electrons can pass through both slits because they do so in possibility.

On the other hand, the particle nature of the electron assures us that whenever we have a setup geared to see the electron as a particle, that's what we are going to see. When we observe each electron passing through a particular slit, we get the pattern on the screen that is characteristic of the particle behavior; the interference pattern is destroyed.

We can understand the destruction of the interference pattern in the following way. Our observation of the electron as it passes through a slit affects it so that its phase coherence with the other probability wave is disturbed. Without the phase coherence, there is no interference pattern.

So the electrons are very delicate. Actually, not only electrons but all microscopic objects are delicate, so much so that even putting a light beam on them disturbs their states. Specifically, the collision of the photon of light changes the momentum of the electron and thus its wavelength (through de Broglie's relation) by an unknown amount, which is enough to destroy the phase coherence of the waves as they arrive at the screen. So instead of the interference, we see the pattern due to electrons passing through individual slits independent of the other.

This result—that if we localize the electron, we necessarily introduce an uncertainty in the momentum of the electron—is called the *uncertainty principle*, which was discovered by Heisenberg. We cannot observe an electron without affecting it. The uncertainty principle thus is a restriction on the measurement process: it restricts our ability to measure the momentum and position of a particle simultaneously.

Another way to understand the dual aspects of our gedanken experiment is to realize that the position and the momentum measurements are really complementary, mutually exclusive processes. We can concentrate on the position, in which case we lose track of the momentum and cannot tell the wavelength of the electron wave, and there is no interference pattern. Or we can concentrate on the wavelength, which we can determine from the interference pattern that results in the double-slit experiment, but now we cannot tell which slit the electron passes through; we have lost track of its exact position. The par-

ticles and waves are thus complementary aspects of the electron, but we can only see one aspect with a given experimental arrangement. This *complementarity principle* is the great contribution of Niels Bohr toward the understanding of quantum mechanics.

To see more clearly how complementarity operates, suppose in the experiment above we make the light that we see the electrons with somewhat dimmer. When we do the experiment with dimmer and dimmer light, we find that some of the interference pattern starts to appear again, becoming more and more prominent (Figure 7.5). When the light is turned off completely, the full interference pattern comes back.

What is happening now is this. As the light gets dim, the number of photons (don't forget that light, too, has a complementary particle nature) scattering off the electrons decreases, so some of the electrons entirely escape being "seen" by the light. The reappearing interference pattern is due to these "unseen," and therefore undisturbed, electrons. Those electrons that are "seen" still appear behind either slit 1 or slit 2, just where we expect them. So the result of this series of experiments can be described by saying that, as the light becomes dimmer and dimmer, more and more electrons escape undisturbed and unobserved, so what we see on the screen becomes more and more like a wave interference pattern. In the limit of strong light, only the electron's particle-nature is seen. In the limit of no light, only its wave nature is seen. In the case of various intermediate light situations, both aspects show up to varied degrees.

A series of pictures illustrates what is going on (Figure 7.6). In the picture on the top left, you can see the man only; this corresponds to our strong-light situation—just as you see only the particle nature of the electron. Then as we progress to the other pictures in

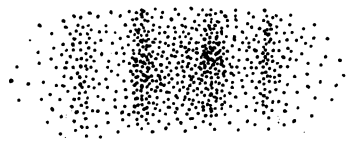

Figure 7.5
Looking with a weak flashlight, we get an interference pattern intermediate between wave and particle.

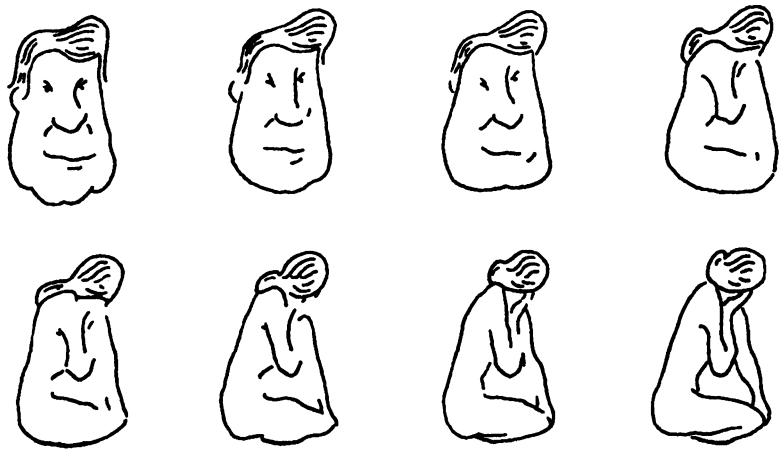

Figure 7.6
The man-girl sequence. (Gerald H. Fischer, "Measuring Ambiguity," *American Journal of Psychology 80*, pp. 541-557 [1967]. Published by the University of Illinois Press. Copyright 1967 by Karen Dallenbach.)

the top row, we begin to see the girl—just as, when we start to make the light dimmer, some electrons defy observation and we start to see the wave nature of the electron. Then finally in the last picture (on the right in the bottom row) only the girl can be seen; this corresponds to when the light has been turned off and it's all wave now for the electrons.

Probability and Uncertainty

Still puzzled with the wave-particle duality? Well, you must comprehend that electron waves are not ordinary waves. What kind of waves are they? Somebody once asked the physicist Richard Feynman this question, and Feynman said, "They are waves of probability in the ocean of uncertainty." In this submicroscopic ocean of quantum potentia, the uncertainty principle demands that the measurement of complementary quantities, such as position and momentum, leaves us with fundamental and unavoidable little errors; in this situation all we can ascertain are probabilities, not certainties.

So the mathematical solution of the Schrödinger equation, technically called the *wave function*, cannot give us the certainty of classical wave motion as Schrödinger and many others originally thought (classical waves can actually be at more than one place at the same time)—that would violate the uncertainty principle. Instead, the solution of the Schrödinger equation gives waves of possibility; so said Max Born. It just tells us probabilistically where the likelihood of finding the particle will be greater; there the wave will be strong. In other places, if the probability of finding the particle is small, the wave will be weak.

For an easy-to-understand example, imagine you are looking for traffic jams from a helicopter above the streets of your city. If the cars were described by Schrödinger's waves, we would say that the wave was strong at the location of traffic jams, and in between traffic jams the wave was weak.

Now one more subtlety. Electron waves are conceived as wave packets because, by employing packets of many waves, using their interference, we can make the wave large only in a specific region of space, and small everywhere else (Figure 7.7). This is important because the wave has to represent a localized particle. And the wave is a possibility wave, and here's what that means quantitatively: for electron waves, the square of the wave amplitude at a point gives us the probability of finding the electron at that point. The

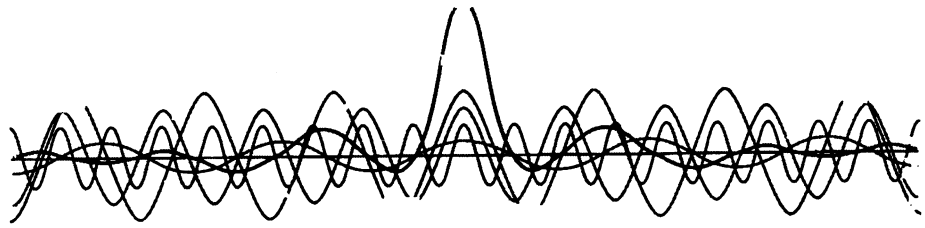

Figure 7.7
Superposition of many packets of waves produces a large wve packet. (Reprinted with permission from P.W. Atkins' *Quanta: A Handbook of Concepts*, published by Clarendon Press, Oxford, UK, [1974].)

electron's wave amplitude is a probability amplitude, the wave function; its square gives a probability distribution, a bell curve with which you may have some familiarity.

If you are not familiar with the bell curve of a probability distribution, here's how you can get one with a little experiment of flipping a coin a few times (your thumb will get tired, but it's worth it). You know that if you flip a coin, there is a 50-50 chance that it will land head up. If you flip a coin 30 times, it will land head up 15 times, on average. Now do 100 of these 30-flip runs and plot the distribution of your results by counting the number of runs that show between 14 and 16 heads, between 22 and 24 heads, etc. The resulting graph will look like a bell curve, centered around fifteen, and tapering off on both sides (Figure 7.8).

So if we square the wave function of a quantum object and plot it, we get a bell curve. Suppose we plot such a bell curve as a function of the electron's position. The curve should center around the expected position, call it x_0, of the electron, and taper off on both sides (Figure 7.9(a)). The width of the curve, as you can see, gives the uncertainty in the electron's position. Call it Δx (pronounced delta ex). If we do the same thing with the probability distribution curve for the electron's momentum (Figure 7.9(b)), we will get the uncertainty of the electron's momentum; call it Δp (delta pee).

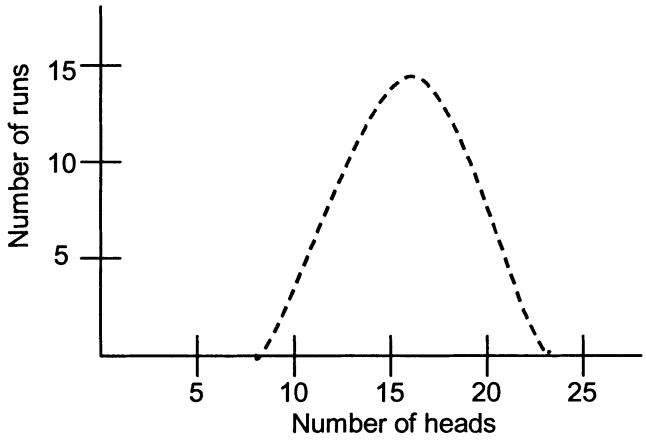

Figure 7.8
A bell-curve graph.

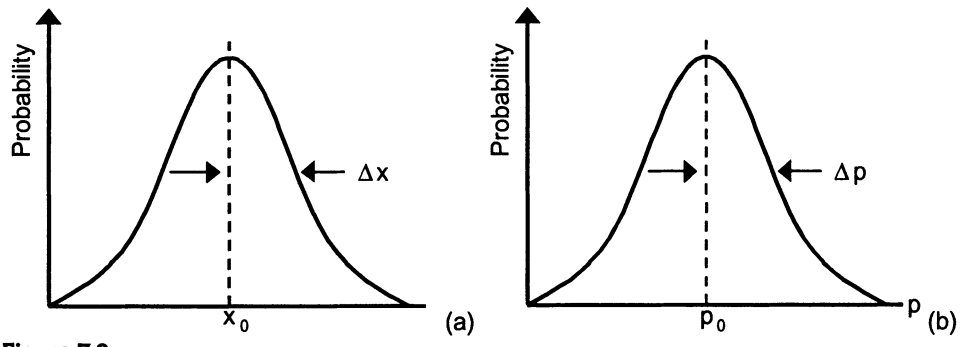

Figure 7.9
(a) The probability that the electron occupies the position x is plotted against x. The uncertainty in the position of the electron is Δx, as shown.
(b) The probability that an electron has momentum p is plotted against p. The momenum uncertainty is given as Δp, as shown.

Now we can write, following Heisenberg, a mathematical statement of the uncertainty principle: the product of the position and momentum uncertainties Δx and Δp is greater than or equal to Planck's constant h divided by 2π (where π is the ratio of the circumference and the diameter of a circle). In symbols,

$$\Delta x \times \Delta p \geq h/2\pi.$$

A little mathematics is often worth a lot of words. This mathematical relationship tells us the meaning of Planck's constant h—the numerical value of h sets the scale of when quantum effects are important. The way things are, h is small, so quantum uncertainty is relegated mostly to the submicroscopic part of our world. If h were numerically larger, there would have been a lot of quantum effects, weirdness, even at the macrolevel!

Probability, Indeterminacy, and Acausality

I have already stated that in quantum mechanics, Bohr's concept of stationary orbits of electrons in atoms has to be replaced by the concept of stationary energy states or energy levels. What happens to Bohr's concept of the quantum leap that the electron takes from one orbit to another to emit light? In quantum mechanics, we must think in a more subtle way: due to the interaction with the electromagnetic field, the electron's state of movement, originally in a stationary energy state, becomes a superposition of such states in possibility. When we measure, one of the possible states becomes actual, and the electron can be said to have made a discontinuous transition, a quantum leap.

Now suppose we ask the question, "When is the electron going to make a quantum jump to a lower energy level?" The answer quantum mechanics gives is this: We do not know precisely. But we can figure out from quantum rules the probabilities; so if we had a very large number of excited atoms, then we could tell the average time of decay for the entire ensemble. But we cannot go beyond that. We have no idea about the precise moment of time a particular electron is going to take the jump in a particular atom.

In the phenomenon of radioactivity, atoms of a certain species undergo a transformation, or decay. Sometimes they become atoms of a different species, emitting energetic subatomic particles in the process. We can detect the radiation with a Geiger counter. The number of ticks of the Geiger counter in a given amount of time tells us the rate of decay of a given radioactive sample. Can we predict such rates of decay of radioactive atoms from quantum mechanics?

For a large assembly of radioactive atoms, quantum mechanics is all we need to calculate the decay rate. That is, from quantum mechanics we can calculate the probability of the decay. So long as we are interested in a large number of atoms, the actual experimental situation, the probability also gives us the rate of decay, on average. But if you consider the decay of a single radioactive atom, precisely when that atom will decay cannot be predicted. The individual behavior is left to chance. This is what Einstein used to object to. "God doesn't play dice," he said many times.

But many physicists think that God does seem to play dice, and quantum mechanics with its probabilistic laws is basically acausal; no precise cause can be determined for the

jump of a particular electron from one stationary state to another. We don't know the specific time of a particular jump, and therefore we cannot assign a specific cause for the jump. The relationship of strict cause and effect in events must now be replaced with one of statistical average cause and average effect; that's all we can know, that's all we can talk about. But this attitude amounts to giving up on quantum mechanics as a valid physics for single objects and single events.

If we accept quantum mechanics for single objects and events, then Einstein's concern stands, "I cannot believe that God would choose to play dice with the universe." There is an alternative to both Einstein and the ensemble apologists. It is to ask squarely, "Who or what converts the quantum possibilities into actual event?" Just because the ensemble behavior is probabilistic does not mean that a single event must also be random, as Einstein feared. Instead, we can see here the role of consciousness, the observer, in single events of quantum measurement. We can think of free will, not the free will of the electrons, as Niels Bohr once thought, but of our free will, in determining the fate of a quantum object in the case of a single event of quantum measurement. But many physicists balk at this way of looking at quantum mechanics (how can consciousness act on matter since consciousness is a material epiphenomenon—isn't it?) and declare, "Nobody understands quantum mechanics."

If you think that this question of a dice-playing God is too remote from your everyday reality, please reconsider. There is a story I read of a young man who thought like you, and his life changed because of the quantum nature of radioactivity. This fellow was a graduate student and was experimenting with a radioactive substance with a known decay rate. "I will do the experiment until I get that many counts, which should take me (on average) two-and-a-half hours. I will catch a bus immediately after and meet my girlfriend." Accordingly, he called his girlfriend to come and meet him at a romantic, isolated spot; he was going to propose to her, you see. Now you can guess what happened. Radioactive decay being probabilistic, what was supposed to take two-and-a-half hours took a little longer; the poor fellow missed the bus. He could not even call his girlfriend. When he finally arrived at where he was supposed to meet her, his girlfriend had already left in disgust and he never saw her again. One little radioactive decay, and what a change in life-plans!

When we cannot understand something, we can joke about it. Here is the artist H. Petard's concept of the quantum mechanical method of catching an African lion: Just set up your cage and wait, he says, because, "At any given moment there is a positive probability that there is a lion in the cage. Sit down and wait." Figure 7.10 is drawn in the same vein.

Like the cartoon character, many physicists today (including this author) don't want to wait a long time for a promissory resolution of quantum paradoxes along a basically Newtonian line of thinking. There is very good reason to believe that quantum physics is opening a window of understanding for us that has the potency of addressing all the shortcomings of Newtonian physics, such as its inability to include consciousness in a reasonable way. Classical physics can look at consciousness only as an epiphenomenon of matter (in which case, how can it have free will? How can it be an independent causal entity?) or as a dual, separate, nonmaterial object (in which case, how can it interact with the material world?).

Figure 7.10
The quantum mechanical method of eating a sandwich. Just hold up your sandwich and wait; at any moment there is a non-zero probability that the sandwich will be in your mouth!

The choice is ours. We can stay put with the pessimist and declare, "Nobody understands quantum physics," or we can revolutionize our science by developing an interpretation of quantum physics beyond the objective statistical interpretation and embrace consciousness (see Part 5).

Question: But if consciousness chooses an actual event out of the possibilities that elementary particles and their interactions produce, and that can be calculated by quantum mathematics, then how come when I look at an object and it transforms from potentiality to actuality, I don't get any feeling whatever of having chosen where it appears?

Answer: Ah, but nature is cunning! The choice must happen in a nonordinary state of consciousness in which all personality and subjectivity in the sense that you are talking about disappears. (See also Chapter 19.)

More on Uncertainty

With the help of the uncertainty principle, we can understand why atoms come in a certain size and why we cannot make them any smaller. There is a science fiction novel by Isaac Asimov, *Fantastic Voyage*, in which it is posited that all objects can be miniaturized to arbitrarily small sizes, a sort of "Lilliput" effect in modern scientific form. The uncertainty principle shows us that such feats are quite impossible. The atomic size represents the uncertainty in the position of the atomic electrons. If we try to localize the electrons further in a smaller region of space, thus reducing their position uncertainty, their momentum uncertainty will correspondingly grow; in other words, the electrons now will have such increased momentum size they will be able to escape from the atom.

Speaking of science fiction, you probably have seen the TV show *Star Trek*. The captain says, "Energize," a lever is pulled down on an instrument panel, and voilá! People standing on a platform disappear as a cloud and reappear from a cloud at a destination that is supposed to be an unexplored planet, or even a wormhole. James Blish, who made *Star Trek* shows into novels, tried to characterize this process as a quantum jump; just as

an electron jumps from one atomic energy level to another without ever passing through the intermediate space, so did the crew of the *Enterprise*. (Other science fiction writers, Poul Anderson and Gregory Benford, for example, have utilized the same idea for futuristic instant movement through large distances.) But you can see a problem with this if you remember all of the messages of quantum mechanics, not just a selected one. When the electron will take the jump, and to where, is acausal and unpredictable, because probability and uncertainty rule the quantum jump. Such quantum transport would force the *Enterprise* heroes, at least occasionally, to wait a long time to get somewhere.

The uncertainty principle also makes it clear that a definite quantum fuzziness defines where the electron is inside the atom. Imagining an electron cloud around the atomic nucleus, as in Figure 7.11, gives a better picture of what is the case, although it is understood that the heavier-shaded regions represent a greater probability of the electron's position than the lighter-shaded regions. Notice that there is no orbit really, although we can loosely define one (the circle in the figure), with its radius equal to the average distance of the electron from the nucleus. Indeed, experimental measurements show that the distribution of the electrons conforms to the idea of electrons existing as a possibility-cloud around the nucleus (Figure 7.12).

There is one more important feature of the uncertainty relation. Suppose you made a measurement of the momentum of an electron. There is no longer any uncertainty in its

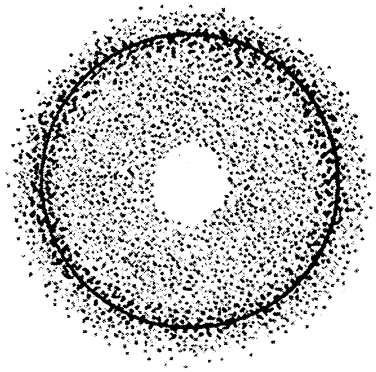

Figure 7.11
The "electron cloud," or probability density of the electron, in the lowest stationary state (the ground state) of the hydrogen atom. The circle denotes an orbit in the average sense.

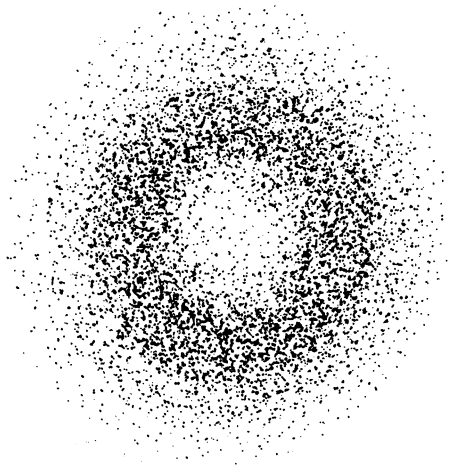

Figure 7.12
The results of repeated measurements of the position of a hydrogen electron in the lowest orbit. The electron's wave usually collapses where the probability for finding it is predicted to be high, giving the fuzzy orbit.

momentum; it is completely known. What can we say about the position of the particle in such a situation? The answer is nothing, absolutely nothing! From the uncertainty relation, taking the equality, $\Delta x \cdot \Delta p = h / 2\pi$, dividing both sides by Δx, and putting $\Delta p = 0$, we get

$$\Delta x = \frac{h / 2\pi}{\Delta p} = \frac{h / 2\pi}{0} \rightarrow \infty.$$

The position is completely uncertain. You might say, "But surely the electron must be somewhere. It's just that we don't know where." No, it is more than that; we cannot even define the position of the electron. So quantum objects are not objects in the sense we are familiar with; they are not like classical objects. They are not particles; they are not even waves in the classical sense. Sometimes they are called wavicles to make this point.

Uncertainty Principle and Zeno's Paradox

An ancient question first raised by the Greek philosopher, Zeno, in his paradox, "The Arrow," goes like this:

> The arrow cannot fly. It cannot fly because an object that is behaving itself in a uniform manner is either continually moving or continually at rest. The arrow is certainly behaving itself in such a uniform manner. Now watch the arrow as it travels along its flight path. Clearly, at any instant, the arrow is occupying a given place. Therefore, if it is occupying a given place, it must be at rest there. The arrow must be at rest at the instant we picture, and since the instant we have chosen is any instant, the arrow cannot be moving at any instant. Thus the arrow is always at rest and cannot fly.

The great philosopher Aristotle understood part of the problem with the paradox. To understand Aristotle's resolution, consider how a filmmaker creates motion out of still frames. If one is careful to remove nonuniformities, then still pictures, when they are run at 24 frames per second before our eyes, can easily generate a sense of continuous motion in our perception. But this is just an illusion. But now imagine running the frames so the time interval between them is infinitesimally small, we are talking about frozen still frames dissolving into one another, no less. We can imagine that we are taking in snapshots of the flying arrow like this, each frame dissolving into the next, giving the arrow its movement. Unfortunately, Aristotle's solution requires an infinite number of still frames passing our eyes each second, an impossible feat!

The philosopher Henry Bergson saw the problem a little differently:

> Passage is movement and stoppage an immobility...When I see the moving object pass through a point...I tend to consider passage as an arrest...All points of space necessarily being fixed, I must be careful not to attribute to the moving object itself the immobility of the point with which it coincides.

Bergson more clearly saw Zeno's real concern, that trying to localize the position of the moving arrow does violence to the fact of its movement.

Heisenberg with his uncertainty principle saw Zeno's real point—that trying to localize the arrow's position messes up its movement. The arrow cannot really be said to occupy a given place and be moving simultaneously in a predictable fashion. Any attempt to take a snapshot of an object gives us its position, but we lose information about its movement.

Zeno was trying to prove that motion is illusory. Heisenberg was saying that we cannot talk about motion without talking about our measurement of it.

Two monks were arguing about the motion of a flag in the wind. Said one, "The flag is moving." "No, the wind is moving," said the other. A master, who was passing by, made the Bergsonian observation, "The flag is not moving. The wind is not moving. Your mind is moving." Heisenberg would have agreed with the master.

Wave-Particle Duality and Quantum Measurement

There are a couple of puzzling questions that we have alluded to before that now must be discussed in more detail. How do we reconcile the wave picture of the electron with the fact that it has particle-like, localized properties? Or, to be specific, does the fact that a free electron spreads out, as a wave must according to the theory of Schrödinger, mean that the electron's charge is now smeared all over space? And the answers are subtle.

It may seem that with wave packets, at least, we should be able to confine the electron in a small place. Alas, wave packets of quantum physics don't stay put! A wave packet that satisfies the Schrödinger equation at a given moment of time has to spread with the passage of time. That's the law of quantum physics.

So at some initial time, we may localize an electron to a tiny dot, but the electron's wave packet will spread all over town in a matter of seconds. And this means that, although initially the probability of finding the electron localized as a tiny dot was overwhelmingly high, it takes only seconds before the probability becomes considerable for the electron to appear anywhere in town. And if we wait long enough, the electron may show up anywhere in the entire country, even in the entire galaxy.

It is this spreading of the wave packet that promotes incessant jokes about quantum weirdness among connoisseurs. Here's a holiday example (a la Petard, quoted above) of the quantum mechanical way of materializing a Thanksgiving turkey: prepare your oven and wait; there is a nonzero probability that the turkey from a nearby grocery store will materialize in your oven.

Unfortunately for the turkey lover, for a massive object like a turkey, the spreading is ever so slow. One may have to wait the entire lifetime of the universe to materialize even a little morsel of Thanksgiving turkey in this way.

But what about the electron? How do we reconcile the spreading of the electron's wave packet all over town with the picture of a localized particle? The answer is that the electron does all that spreading in *possibility*. But then, who or what makes actuality out of possibility? We must include the act of observation in our reckoning.

If we want to measure the electron's charge, we intercept it with something like a cloud of vapor, as in a cloud chamber. As a result of this interception, we must assume that the electron's wave packet collapses, so now we are able to see the electron's track

through the cloud of vapor (Figure 7.13). As Heisenberg said, "The path of the electron comes into existence only when we observe it." When we observe it, or measure it, we always find the electron localized as a particle. We may say that our measurement "reduces" the electron's spreading wave to a localized particle.

When Schrödinger introduced his wave equation, he and others thought that perhaps they had purged physics of quantum jumps—of discontinuity—since wave motion is continuous. But the particle nature of quantum objects had to be reconciled with the wave nature, and thus wave packets were introduced. Finally, with the recognition of the spreading of the wave packet and with the realization that it is our observation that must instantly collapse the size of the packet, we see that the collapse has to be discontinuous (continuous collapse would take time since it would be limited by the Einsteinian speed-of-light limit).

So how about an electron in flight from this perspective? In fact, for any submicroscopic projectile, when we make an initial observation on it, we find it localized in a tiny wave packet, as a particle. But after the observation, the packet spreads—the spread of the packet is the cloud of our uncertainty about the packet. If we observe again, the packet localizes once more, but it always spreads between our observations (Figure 7.14). Keep this picture of the movement of quantum objects always in your mind.

Watching electrons, said the physicist-philosopher Henry Margenau, is like watching fireflies on a summer evening. You can see a flash here and another twinkle of light there, but you have only some idea of the possibilities and probabilities of where the firefly is between your observations. You cannot define a trajectory for it with any confidence. Even for a macroscopic object, such as the Moon, quantum mechanics predicts essentially the same picture, the only difference being that the spreading of the wave packet is imperceptively small (but nonzero!) between observations.

If you have a hard time believing that a macroscopic object actually moves from its classical trajectory when we are not looking at it, this movement has been measured for a one-ton apparatus in the laboratory. The movement indeed is quite small, 10^{-17} centimeter, but modern laser measurements have made it possible to ascertain it.

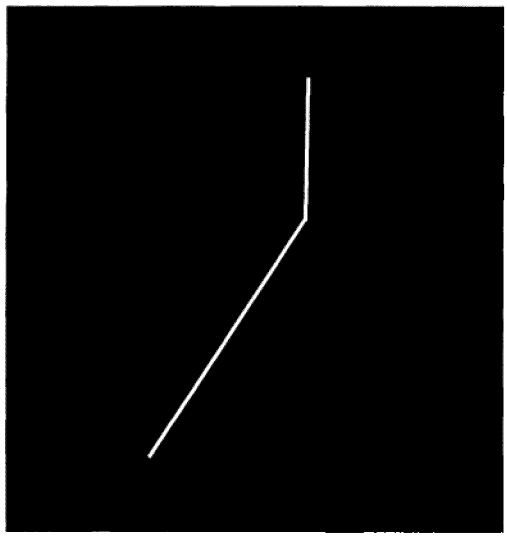

Figure 7.13
An electron's track through a vapor cloud.

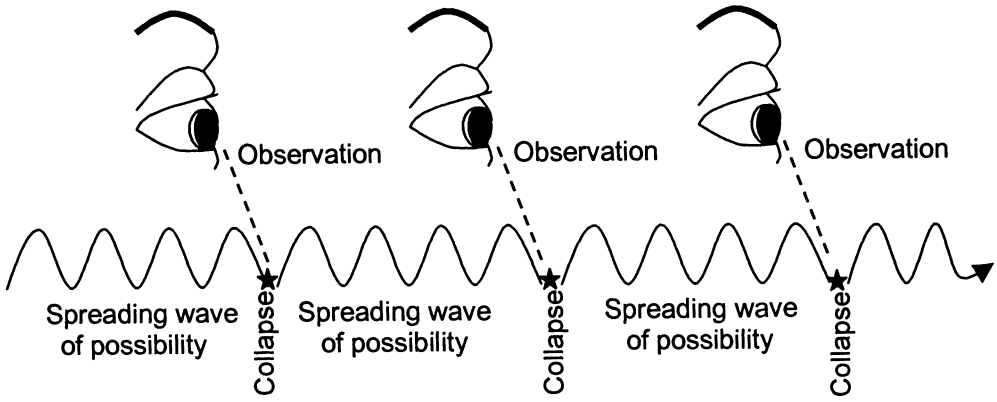

Figure 7.14
An electron spreads out in a wave of possibility and potential, but when we observe the electron, the possibilities collapse into a single localized event.

We are now really getting to the crux of the matter! Whenever we measure it, a quantum object always appears at some one place, as a particle. The probability distribution simply identifies the place or places where it is likely to be found when we do measure it—no more than that. On the other hand, when we are not measuring it, the quantum object spreads, and it does "exist" in more than one place at the same time, as a wave, as a cloud in transcendent potentia (to use Heisenberg's term)—no less than that.

The Correspondence Principle

It would be grossly inaccurate, once some of the revolutionary ideas of the new physics are grasped, to think that the old classical Newtonian physics is all wrong. The old physics lives on in the realm of most bulk matter (but not all) as a special case of the new physics. This is one important characteristic of science. When a new order of science replaces an older one, it usually extends the arena of science. In the old arena the mathematical equations of the old science still hold (remember, they are verified by experimental data). Macrobodies, with their large masses, spread extremely slowly as waves of possibility, so slowly that in most cases we can ignore the spreading and quantum uncertainty altogether.

Thus, in the domain of classical physics, the deductions of quantum mechanics for the motion of objects correspond clearly to those that are made using Newtonian mathematics, as if the bodies we were dealing with were classical. This is called the *correspondence principle* and was formulated by Bohr.

The relationship between classical and quantum physics in some cases resembles the "gestalt" picture, "My wife and my mother-in-law" (Figure 7.15). What do you see in this drawing? Initially, you see just the wife or just the mother-in-law—I always see the mother-in-law first. It may actually take you a while to discover the other image in the drawing.

Suddenly, if you keep at it, the other image emerges, the mother-in-law if you started with the wife. The wife's chin transforms into the nose of the mother-in-law, her neckline into the chin of the older woman, and so on. What's going on, you may wonder. The lines are the same, but suddenly a new way of perceiving the picture has become possible for you. And very soon you find that you can easily go back and forth between the two pictures, the old and the new. You still see only one of the two images at any given time, but your consciousness has enlarged so that you are aware of the duality. In such an extended awareness, the strangeness of quantum physics begins to make sense. It even becomes exciting. Paraphrasing Hamlet's comment to Horatio, there are more things in Heaven and earth than were dreamt of in classical physics.

Quantum mechanics gives us a wider perspective, a new context that extends our perception into a new domain. We can see nature as separate forms, as either waves or particles, or we can discover complementarity, the idea that both waves and particles are inherent in the same thing.

Figure 7.15
"My Wife and My Mother-In-Law" (after W.E. Hill).

Bibliography

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Tarcher/ Putnam, 1995.

March, R. *Physics for Poets*. NY: McGraw Hill, 1978.

Wolf, F.A. *Taking the Quantum Leap*. San Francisco: Harper & Row, 1981. Zeno's paradox, "The arrow," is discussed well in this reference. Altogether a good introduction to quantum ideas.

Herbet, N. *Quantum Reality*. NY: Dutton, 1986. A good introduction to the various interpretations of quantum physics.

Part THREE

QUANTUM PHYSICS COMES OF AGE

CHAPTER 8

The Copenhagen Interpretation

Let's summarize the introduction in the last few chapters to the quantum mechanical view of nature, a view that is essential to the understanding of the behavior of submicroscopic particles. It began with Max Planck who, with his formula

$$E = h\nu,$$

succeeded in developing a theory of blackbody radiation that agreed with experiment. Then Albert Einstein developed the concept of the photon in order to explain the photoelectric effect. Niels Bohr injected the idea of quantum stationary states of the electron and built a successful model of the atom on that basis.

The final piece of the puzzle was the work of three scientists. The first, de Broglie, introduced the idea of matter waves obeying the relation

$$\lambda = h / p.$$

The other two, Heisenberg and Schrödinger, completed the quantum mechanical picture by developing the mathematical equation obeyed by the new mechanics, the equation that replaces Newton's second law of motion in the submicroscopic domain of nature. In the end we have a remarkably complete theory, so far as the prediction of experiments is concerned.

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Conceptually, the quantum mechanical theory introduces very large departures from the classical view of nature. Matter and light both are recognized as dual—as both particle and wave. But matter waves are not like ordinary waves; they must be interpreted as possibility or probability waves. Thus the statistical concept of probability enters physics, and physics no longer is expressible in completely deterministic terms. The indeterministic character of the submicroscopic world is summarized by the Heisenberg uncertainty relation:

$$\Delta x \ \Delta p \geq h / 2\pi.$$

The duality of matter can be understood from the principle of complementarity. A complete view of nature can be obtained only as separate polar opposites, like particles and waves; the quantum reality consists of transcendent potentia, it is beyond duality, it is beyond space-time, which is where duality reigns. Another important aspect of quantum mechanics is the inseparability of quantum systems and their measurement. Finally, classical physics is restored for the macro domain of nature via the correspondence principle.

To put it succinctly, according to the above *Copenhagen interpretation* of quantum mechanics developed by Born, Heisenberg, and Bohr, we calculate quantum objects as waves and interpret the waves probabilistically. We determine their attributes, such as position and momentum, somewhat uncertainly, and we understand them complementarily. In addition, the Copenhagen interpretation regards discontinuity and quantum jumps—for example, the collapse of a sprawling wave packet upon observation—as a fundamental aspect of the behavior of a quantum object. There is also an aspect of inseparability. Talking about a quantum object without talking about how we observe it is ambiguous. Finally, for massive macro-objects, quantum mechanical predictions smoothly match those of classical physics. This introduces a suppression of such quantum effects as probability and discontinuity in the macrodomain of nature that we perceive directly with our senses. Classical correspondence camouflages the quantum reality.

Cutting Through Classical Prejudices

Let's now see how these principles of quantum theory enable us to discard the worldview of classical physics whose assumptions are:

1) Objectivity;
2) Causal determinism;
3) Locality;
4) Continuity; and
5) Material monism. (See Part 1 of this book for the history of these prejudices.)

Assumption 1): *Objectivity*. A basic assumption that the materialist makes is that there is an objective material universe out there, one that is independent of us. This assumption

has some obvious operational validity, and it is often assumed to be necessary to conduct science meaningfully. But is this assumption really valid? The lesson of quantum physics is that we choose which aspect—wave or particle—a quantum object is going to reveal in a given situation. Moreover, our observation collapses the quantum wave packet to a localized particle. Subjects and objects are inextricably mixed up. And if subjects and objects are mixed up, how can we uphold the assumption of objectivity, at least when it is stated strongly as above?

Question: Can science be done without objectivity?

Answer: Obviously, science cannot be rid of objectivity completely. So we have to opt for some form of weak objectivity. Quantum mechanics shows what this form of weak objectivity is. On one hand, we have, like statistical determinism, statistical objectivity. For large ensembles or for a large number of events, randomness prevails and the effect of the subject-intervention disappears. For single measurements, it must be assumed that the measurement be observer-invariant. In other words, the result of the measurement should not depend on who the observer is, you, me, or somebody else.

Assumption 2): *Causal determinism*. Another assumption of the classical scientist that lends credence to material realism is that the world is fundamentally deterministic. All we have to know are the forces acting on each object and the initial conditions—the initial velocity and position of the object. But the quantum uncertainty principle says that we can never determine both an object's velocity and its position simultaneously with absolute accuracy. Therefore, there will always be error in our knowledge of the initial conditions, and strict determinism does not prevail. In fact, the idea of causality itself is suspect. Since the behavior of quantum objects is probabilistic, a strict cause-effect description of the behavior of a single object is impossible. Instead, we have statistical cause and statistical effect when talking about a large group of particles.

Assumption 3): *Locality*. The assumption of locality—that all interactions between material objects are mediated via local signals, signals that move through space with a finite velocity taking a finite time—is crucial to the classical physics view that objects exist essentially independent and separate from one another. But if waves spread over vast distances and then instantly collapse when we take measurements, then the influence of our measurement is not traveling locally (see also Chapter 15).

Assumption 4): *Continuity*. In classical physics, motion is continuous, but in quantum physics there are discontinuous quantum jump, the discontinuous collapse of a wave packet. Gone with continuity is also the view that there is a complete mathematical description of reality.

Assumption 5): *Material monism*. Underlying classical physics and its previous four prejudices is the most limiting prejudice of them all, materialism, the idea that everything is made of matter (and its correlates, energy and force fields), elementary particles, that all things are caused by elementary particles and their interactions. But quantum physics has challenged strict materialism also from the beginning. If subjects are involved in determining the nature of reality, what will manifest, wave or particle, in a given measurement, can we escape giving the subject causal efficacy? If determinism is not valid in physics

except in a statistical sense, if there is free choice involved in determining the result of a single quantum measurement, then whose choice is it? Who or what makes the possible movements of elementary particles into actual manifest movement? These haunting questions force us to look beyond materialism.

Thus, notwithstanding the correspondence principle, the new paradigm of physics—quantum physics—contradicts the dicta of classical physics—there is no way around it. We cannot say, citing correspondence, oh, classical physics holds for macro-objects for all practical purpose, and since we live in the macroworld, let's assume that the quantum strangeness confines itself to the submicroscopic domain of nature. The strangeness haunts us all the way to the macrolevel.

The Dancing Wu Li Masters

The journalist Gary Zukav wrote a book very appropriately named *The Dancing Wu Li Masters*. *Wu Li* in Chinese means physics in English. Thus, the book is about dancing physicists, if translated literally. Surprise! It's not about the dance, but the dancer. In classical physics, the dancer is irrelevant; only the dance—the play—counts. But not so in modern physics. To talk about the dancers is to talk about the dance. So let's take time out to look at the style of the quantum *Wu Li* dancers, a few representative ones, at least.

Take a dreamer—for example, Werner Heisenberg. He was a disciple of Neils Bohr, from whom he very likely learned the art of creative dreaming. Bohr himself reportedly made his most celebrated discoveries through the process of dreaming. So when young Heisenberg got stuck with the very difficult problem of figuring out the equations of the mechanics of the atom, what did he do? He ate a big dinner and went to sleep. And—Lo and behold!—Heisenberg saw *the* dream. He dreamed of his physical quantities as represented by arrays of numbers. But these arrays of numbers were funny. Unlike ordinary numbers, they did not commutate with each other, which means $a \times b$ was not equal to $b \times a$, if a and b were two such arrays of numbers.

Ordinarily one wouldn't think of representing physical quantities by noncommutating objects, especially if nobody had done it before. But in a dream everything is possible. This dream was so special, of course, because the idea of representing physical quantities by noncommutating mathematical entities was the crucial piece of information that Heisenberg needed to write down his equation of quantum mechanics.

Wolfgang Pauli's (whose monumental work in quantum physics will be described in Chapter 10) recognition as the outstanding theoretical physicist of his time was cemented when an experimentalist discovered the so-called Pauli effect. One day in a certain laboratory in Germany, an experimentalist had set up his apparatus and started to perform an experiment. All of a sudden the apparatus broke down for no reason at all. Nothing worked for a while. But after a time the experimental setup abruptly started working again. What happened? It turned out that Pauli was passing through the town on a train near the laboratory during the exact period that the apparatus would not work. This was the Pauli effect: experiments did not work in Pauli's proximity.

Some of the quantum physicists were very talkative. The first prize in this depart-

ment must go to Niels Bohr himself, the dean of the physicists of the quantum era. Just after Erwin Schrödinger discovered his famous equation, Bohr invited him to Copenhagen to discuss Schrödinger's work. Little did Schrödinger, who was not well acquainted with Bohr, know what he was in for! In the few days that Schrödinger was enveloped in the hospitality of the famous Bohr mansion, Bohr wore him out so completely with his constant barrage of questions, comments, and inquisitions that Schrödinger exclaimed in exasperation, "I would never have discovered my equation if I knew..."

Of course, there are exceptions. For example, Paul Dirac, who developed the relativistic generalization of the Schrödinger equation, was downright miserly with words. Once Dirac was giving a seminar lecture that consisted of a lot of mathematics, which he wrote down on the blackboard. After the talk, the chairman of the seminar asked for questions from the audience. A gentleman stood up and said, pointing to one of the equations on the blackboard, "Professor Dirac, I don't understand that equation." Everybody waited for Dirac's answer, but nothing was forthcoming. Finally, when the chairman asked, "Professor Dirac, aren't going to respond to the question?" Dirac calmly said, "That was a comment, not a question."

All of the quantum masters were highly original and capable of going way beyond the thinking of their contemporaries. Richard Feynman, perhaps the most colorful of all the physicist-personalities to create quantum physics, stated it best to his first wife (who died very young): "What do you care what other people think?" His wife often reminded Feynman of this statement whenever the occasion arose.

The next story, about Einstein, perhaps reflects a most important and fairly common trait among truly great people—modesty. At the time of this incident, Einstein was already a legend. It happened in the small university town of Princeton, New Jersey, where Einstein worked at the Institute for Advanced Studies. One day he and his assistant, Leopold Infeld, went to see a movie. When they found upon entering the theater that the movie would not start for fifteen minutes, Einstein expressed the desire to take a walk. But the gatekeeper had already taken their tickets, and Einstein became quite concerned about getting back in again. He insisted that the gatekeeper take a good look at their faces so that he would recognize them when they returned. The gatekeeper was quite amused. "Yes, Professor Einstein, I will recognize you," he assured him.

This final story was improvised to make a point—what point depends on your point of view. I heard it from an associate of Werner Heisenberg. The hero (?) of the story is Wolfgang Pauli, the master logician among the quantum dancers (see Chapter 10 for Pauli's important discovery in quantum physics). The story begins when Pauli dies and goes to heaven, where presumably most physicists end up after they die. Pauli's friends who are already in heaven rejoice on this auspicious occasion and give him a hero's welcome, highlighted by an appointment with God Him/Her/Itself. When Pauli arrives in God's office, he finds God working away at a desk (don't be surprised that God works in an office at a desk—we all fashion God in our own image, even theoretical physicists). Without preamble, Pauli asks God the ultimate physical question, "Tell me, God, how did You do it? What's the ultimate mathematical equation that rules the workings of the universe?" God goes to the blackboard (of course, God—the best mathematician around—has a blackboard!) and writes down a very complicated equation. Pauli studies it for a few minutes before declaring, "I've tried it! It doesn't work!"

Bibliography

Goswami, A. *The Cosmic dancers: Exploring the Physics of Science Fiction*. NY: Harper & Row, 1983.

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Tarcher/ Putnam, 1995.

Zukav, G. *The Dancing Wu Li Masters: An Overview of the New Physics*. NY: Bantam, 1980.

CHAPTER 9

Atoms and Light

The poet Louise McNeill wrote quite imaginatively about electrons cascading down their atomic orbits: "Hush–the electrons sing / Dropping / Down / Through their orbits / From ring / To glowing ring / Lower / And lower / Hush."* But she forgot the quantum leap. (Her word "dropping" conveys the notion of continuous movement.) The first triumph of the new quantum theory of the atom came from the analysis of the light emitted by an atom as one of its electrons jumped from a level of higher energy to one of lower energy, which showed clearly the discontinuous discreteness of atomic transitions.

How can we study the light from an individual atom? As you know, a solid when hot emits continuous radiation. The atoms in a solid are packed so closely together that they affect each other too much. The "music" each makes gets mixed with that of its neighbors' and all that comes out is noise, optical noise, which is what the continuous radiation is. So in order to study the "music" of each atom, we have to get it in a relatively free state of existence.

Fortunately, this is not very hard to do since it is known that in the gaseous state atoms are practically free of interaction. So all we have to do is look at the light emitted from a heated, dilute gas to observe the spectra of the atoms.

Historically, physicists studied the light from a heated gas without having a clear notion of why they were doing it. They found that it is easier to get light from a gas by exciting it electrically. To this end they put a little of the gas in an evacuated tube and

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passed an electrical spark through the gas. Then they studied the light that was emitted with a simple prism arrangement (Figure 9.1). To their surprise they found that the light consisted of individual lines. Since light of different wavelengths was dispersed by different amounts, by noting the place on the screen where a particular line appeared, the wavelength of that line could be determined.

Thus, these spectroscopists, as experimenters of optical spectra are called, amassed a huge amount of data on the lines of light (more formally called *line spectra*) emitted by various gases. The most famous of all these spectral data came from a German school teacher named J. J. Balmer in his work on the hydrogen atom (Figure 9.2).

When Niels Bohr was working out the details of his theory of the hydrogen atom around 1913, one of the first things he did was to apply his theory to the calculation of its line spectra. In this theory the line spectra of the hydrogen atom were due to the transition of the atomic electron from various excited higher energy levels to lower levels. Bohr could determine the energy of the light of the lines using Planck's formula $E = h\nu$, except E now was the difference of energy between the two levels involved in the transition.

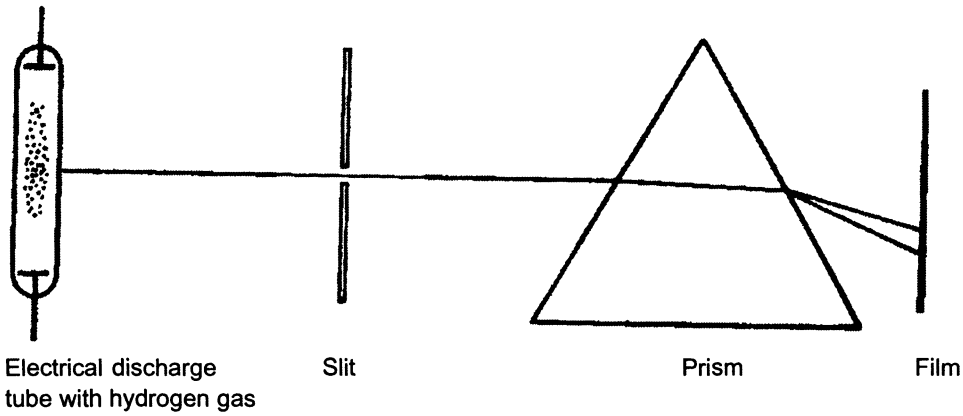

Figure 9.1
An arrangement for the study of the emission spectra of gases.

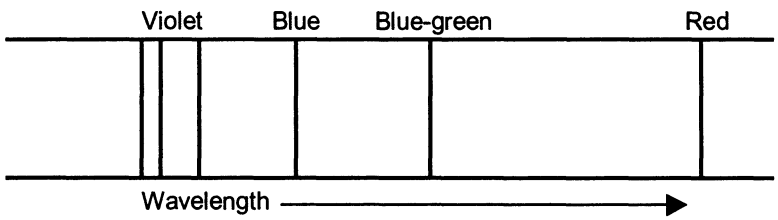

Figure 9.2
The Balmer lines of the hydrogen atom. There are other lines in the hydrogen spectrum, but these played a very special role in the development of the Bohr atomic theory. Wavelength is speed of light divided by frequency.

Calling E_i and E_f the energies of the initial and final energy levels, respectively, the frequency of the photon emitted was given as

$$h\nu = E_i - E_f$$

or

$$\nu = \frac{E_i - E_f}{h}.$$

Since Bohr's theory had only a few discrete energy levels for the hydrogen electrons, he predicted only a few discrete frequencies, or spectral lines. For each final level *f*, corresponding to the various initial states *i* (that are higher in energy), he predicted a series of spectral lines related by very simple formulas.

Imagine Bohr's surprise, then, when somebody told him that such correlation of the spectral data of hydrogen into different series already existed. A few hours of intense excitement, and he had it. His theory explained all the known spectral data for the hydrogen atom, including those of Balmer. Each of the Balmer lines was due to the transition of an electron from one of the higher levels to the first excited state (Figure 9.3).

The excellent agreement of Bohr's theory with the spectroscopic data was what made people interested in the quantum theory of the atom. When Einstein heard about this, it is said that his eyes became big, and he said softly something to the effect that this will be considered one of the best pieces of physics ever done.

Later, when quantum mechanics was established with the discovery of the Schrödinger equation, the now complete theory gave the same result as Bohr's tentative theory in the simple case of hydrogen. Since then quantum mechanics has been able to explain many more of the spectral data and to predict new ones, later verified.

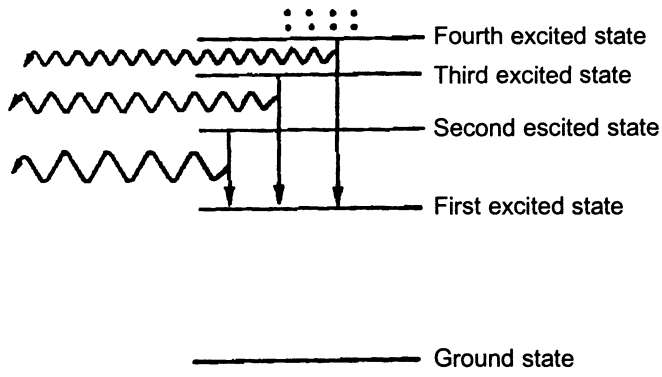

Figure 9.3
How Bohr explained the Balmer lines. Each line is due to a transition from a higher excited state to the first excited state of the hydrogen atom. The calculated frequencies agree with the experimentally observed frequencies of the lines.

Absorption Spectra

When light falls on an atom, if the energy is right—that is, if $h\nu$ for the photon matches the difference of energy between two levels of the atom—the atom will absorb the light. The absorption gives rise to dark lines in the otherwise continuous spectrum of a solid or of some other source that has been contaminated by a few gaseous atoms (Figure 9.4). The sun's own spectrum showed quite a few of these dark lines under the careful scrutiny first carried out by German physicist Joseph Fraunhofer (hence the lines are called Fraunhofer lines). The dark *absorption lines* match exactly the frequencies of the emission lines from the same gases. Thus looking at the absorption lines of the spectrum of a star is one way to determine the chemical composition of that star. The element helium was discovered through the observation of its absorption lines in the solar spectrum. The name helium (from the Greek *helios*, meaning "sun") is a reminder of its discovery story.

Fluorescence

The formula $E = h\nu$ makes clear that the energy of a photon increases in direct proportion to its frequency. Ultraviolet light, with a greater frequency, has more energy than visible light. In fact, an ultraviolet photon has just enough energy to disrupt molecules of the human body, knock electrons out of it, and so on. This is the reason that you get a sunburn; the ultraviolet component of the sunlight does the trick. The visible parts of sunlight are quite harmless.

There is a phenomenon called *fluorescence* in which ultraviolet photons are absorbed by some atoms, which then emit low-energy photons; this is the basis of the fluorescent lamp. A fluorescent lamp in its essential features is shown in Figure 9.5. Basically, it is a glass tube filled with mercury vapor at low pressure, containing a hot filament that emits electrons near the base of the tube, and with a coating on the inside surface of the tube of special fluorescent atoms. The electrons from the filament collide with the mercury atoms and excite their electrons to high energy levels. When the electrons de-excite to lower levels, high-frequency ultraviolet light is emitted. The energy of the photon is equal to the difference of energy of the two electronic levels. The atoms of the coating now absorb some of these ultraviolet photons and transfer some of their electrons to higher energy levels. But the energy level structure of the atoms in the coating is such that when their electrons de-excite, only photons of lower energy in the visible spectrum are emitted.

The transition of an electron from each higher energy level to a lower one gives a

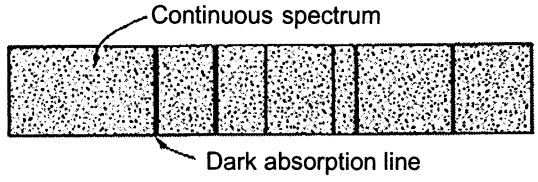

Figure 9.4
Absorption lines in the background of a continuous spectrum.

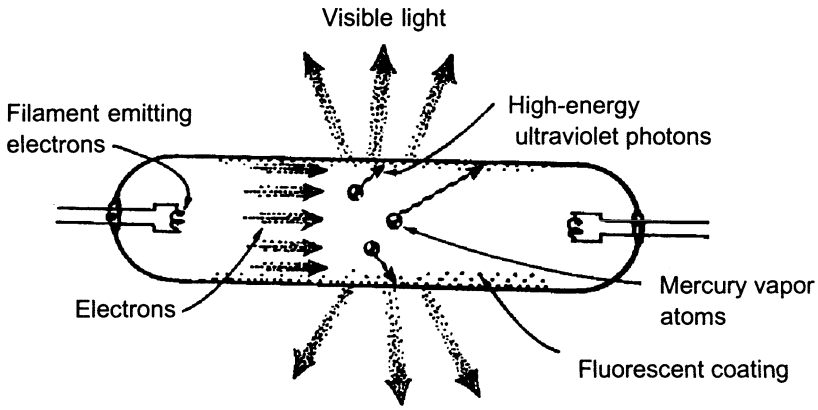

Figure 9.5
A flourescent lamp.

photon of a characteristic frequency or color and a sharp line in the spectrum. Usually there can be several such lines, and their mixture determines the color of light that we get from the lamp.

Do Blondes Have More Fun?

The spectral distribution of fluorescent light is compared with those of incandescent light and regular daylight in Figure 9.6. Notice how different the spectral contents are: sunlight distribution is quite even in all the colors, the fluorescent is distributed fairly evenly in short wavelengths but the intensity tapers off at the long-wavelength end, and the incandescent is rich in long wavelengths. So the color of an object, which depends on the wavelength distribution of light reflected from it, can vary quite a bit between the three kinds of light. For example, hair that looks yellow in regular daylight reflects equal amounts of red and green. So the same "blonde" hair will look reddish in incandescent light, since the incandescent light has more red than green, and so will reflect red more copiously. And in fluorescent light, the same hair will tend to look greenish, because fluorescent light has little red to reflect to balance the green.

Do you still believe that blondes have more fun? Since how you dress in fashionable society depends on the color of your hair, a blonde person will have to dress differently in different kinds of lighting or face fashion disgrace.

The Laser

The *laser* is an acronym for Lightwave Amplification by Stimulated Emission of Radiation. The most important feature of the laser is that it gives a very intense beam of light of a single wavelength. It also gives a unidirectional beam of light, not a spherical wave but a plane wave (see Volume I of this book for definitions). Let's now try to understand how it does these things.

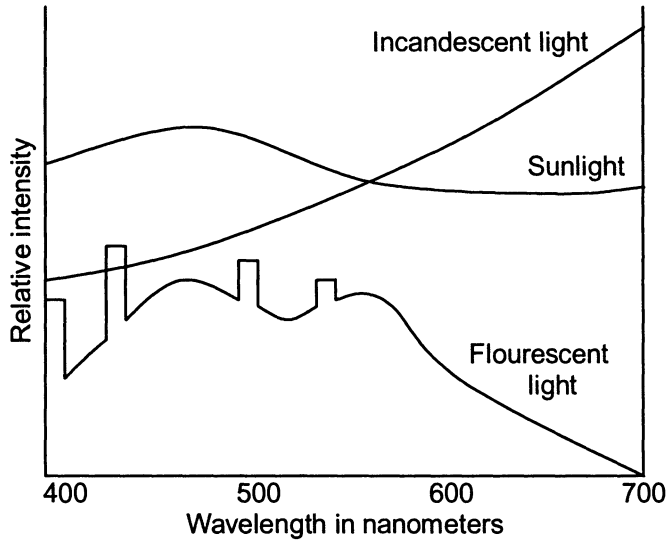

Figure 9.6
Comparison of the spectral distribution of flourescent light, incandescent light, and regular daylight.

Figure 9.7 shows a ruby laser, which uses a pink ruby rod with a partially reflecting mirror at one end. Ruby is an oxide of aluminum (a chemical compound of aluminum and oxygen atoms) with just about five parts in ten thousand of an oxide of another metal, chromium. Very intense ultraviolet photons from a flashtube filled with the gas xenon are directed into the ruby rod. The electrons of the chromium atoms are lifted to a specific long-lived higher energy level, called a *metastable* state, by the incident photons. A few of these electrons come down to the ground level spontaneously and make red light in the process. And now a most interesting thing happens. The red photons, upon being reflected from the mirror at the end, fall back on the metastable excited chromium atoms. This causes a *stimulated emission* of radiation from the chromium atoms—an emission characterized by phase coherence; when an atom de-excites after being stimulated by a

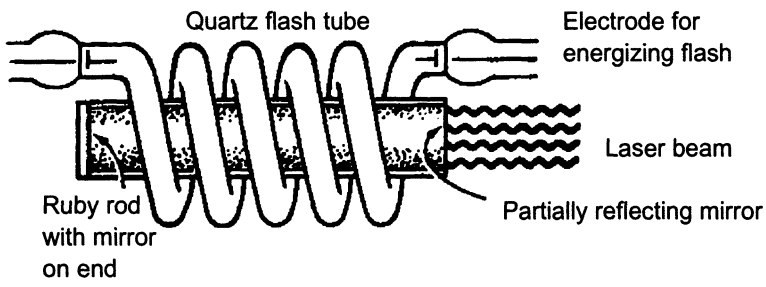

Figure 9.7
A ruby laser.

passing photon, it emits a photon that is in phase with the stimulator photon (Figure 9.8). Note also that each event of stimulated emission multiplies the number of photons by two. The total effect is a phase-coherent pulse of single-frequency phase-coherent photons that can be very intense as compared to ordinary, incoherent light (Figure 9.9). If all the light waves coming from a source dance in unison, in perfect coherence, the togetherness gives the beam extra punch. So the key to a laser beam's intensity is really stimulated emission. The laser can be such a concentrated beam of energy that it can burn a hole in a steel plate, as you may have seen.

The fact that laser light is single-frequency coherent light gives us another technological possibility. A laser wave can be modulated just as a radio-frequency wave can. Thus, a laser wave can carry information such as speech or music and can be used in long-distance

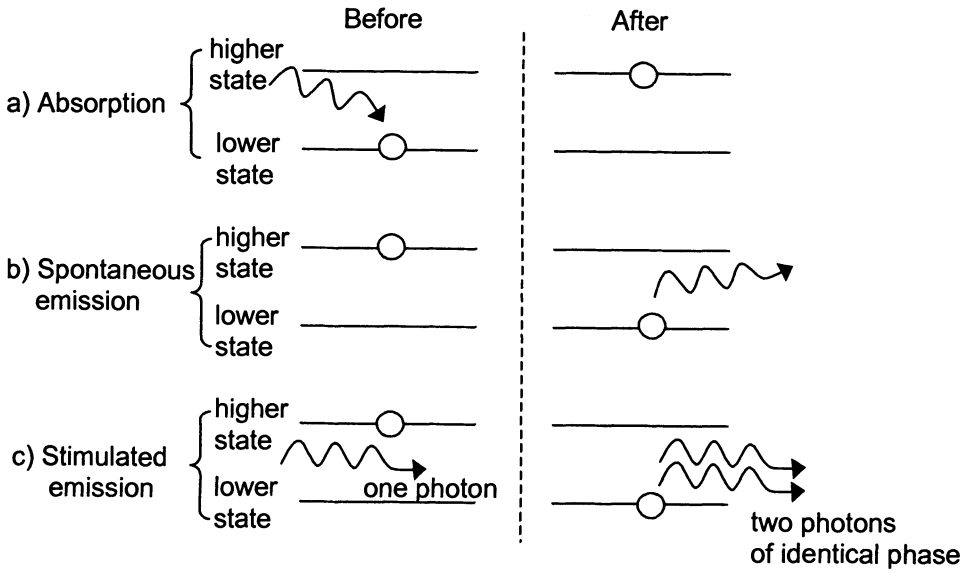

Figure 9.8
Emission of two photons that are in phase when an atom is stimulated by a photon, and then de-excites.

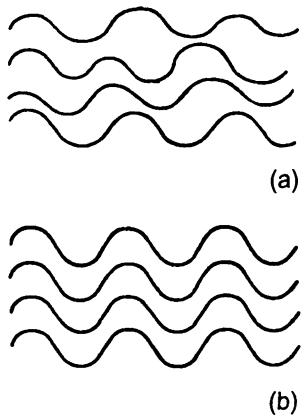

Figure 9.9
(a) Waves out of phase; an ordinary light beam is like this.
(b) Waves in phase; laser light.

communication. The use of laser in communication (called light-wave communication) is revolutionizing long-distance telephone communication.

Stationary Waves in the Laser

The mystery of the unidirectionality of the laser beam is stationary waves. Let's see how.

Light waves interfere, so we can make stationary waves of light by confining them in a small region of space. A mirror, only partly reflecting (so that some of the light leaks out), is used at one end, and the other end has a completely reflecting mirror. Stationary waves are generated by virtue of the interference of the traveling waves back and forth, but for only those waves that are exactly aligned with the axis of the device. The result is a unidirectional beam (Figure 9.10). Also, in this case, the number of wavelengths that fit inside the length of the tube is very large, on the order of hundreds of thousands.

Thus, one of the most interesting things about laser beams is that they are straight and narrow as they come out of the apparatus, and they more or less stay that way. This is very different from ordinary light beams, which are spherical waves spreading in all directions. In contrast, a laser beam consists of plane waves. So one reason the laser beam retains its intensity so well with distance is that it does not spread as it travels, whereas the light beam from an ordinary source does. The range of the laser beam consequently is spectacular. A laser beam starting from earth can illuminate the surface of the moon. Experiments have been done to determine the exact position of the moon at various times by using range finding with a laser beam.

Holography

No discussion of lasers is complete without the mention of ***holography***, or "holistic photography." This is the use of a laser beam to produce a three-dimensional picture of an object by using a method first suggested by physicist Dennis Gabor. The arrangement is shown in Figure 9.11. The laser beam is spread out by means of a lens in order to illumi-

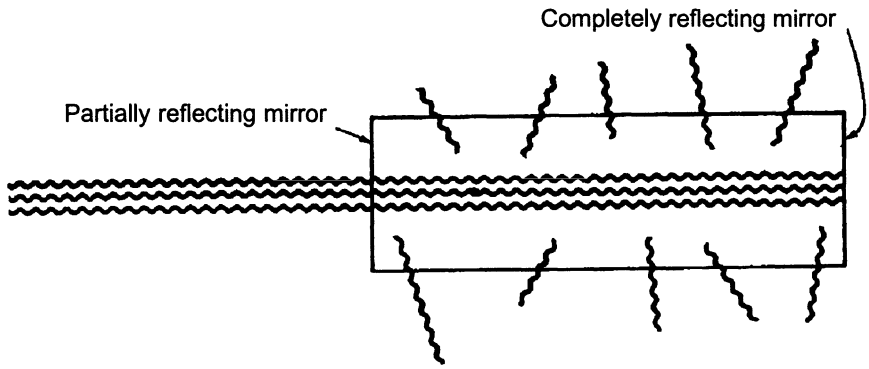

Figure 9.10
The laser beam is aligned well with the axis of the laser tube because of the stationary wave principle.

nate the whole body of the object to be holographed. After the spreading is accomplished, the beam is split in two by means of a half-silvered mirror. One part of the split beam is directed by means of a second mirror onto the hologram film directly: this is called the reference beam. The other part is directed onto the object and is reflected by it. The reflected beam from the object forms an interference pattern with the reference beam at the location of the film, which records the interference pattern. This is the hologram: it is an interference pattern. If you look at a hologram, all you see is a pattern of whirling lines in which, however, is recorded the whole picture of the original object (Figure 9.12).

In order to retrieve the picture, you have to shine a monochromatic laser beam on the hologram and then look through the hologram (Figure 9.13). The picture is virtual, seen on the other side of the hologram. The picture is also three-dimensional, as you verify by shifting the angle of your vision. The image is virtual; you can't touch it, but it looks like the real object in just about every respect.

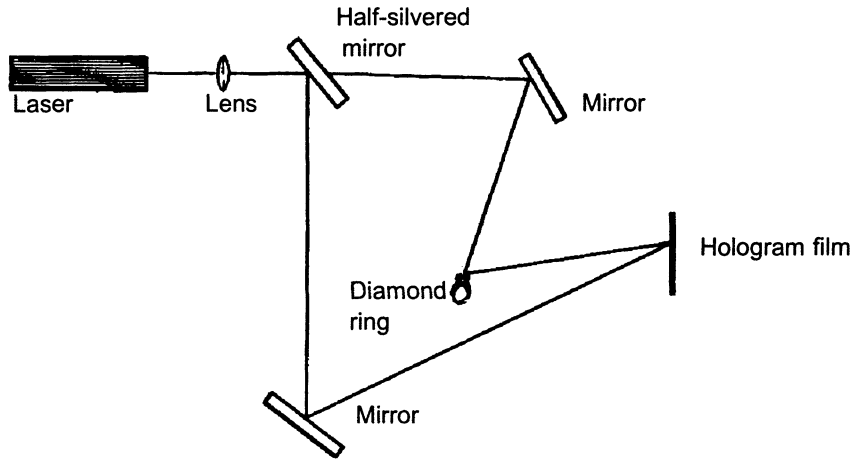

Figure 9.11
An arrangement for making a hologram.

Figure 9.12
A hologram can look like this; it is just a complicated interference pattern of bright and dark lines.

Modern technology has given us many improvements of the basic hologram, for example, the white light hologram, which uses thin film technology to retrieve the image even with ordinary white light. Another interesting innovation is the multiplex hologram where a motion picture-like effect is obtained by combining several holograms.

One important aspect of the hologram is that every little part of it has the complete picture. The record was made without the use of a lens to focus the beam on the film. Thus every point of the film had a piece of light from every part of the object. So you can tear off a little part of the hologram and you still have the whole picture (although it loses some of its clarity). A part is also the whole with a hologram.

Is Memory Holographic?

The idea of hologram has been applied toward understanding why memory storage in the brain is not localized. Originally, it was hypothesized that the brain stores memory in localized "ingrams," but such ingrams are difficult to locate. Instead, there are experiments by the neurophysiologist Karl Lashley that suggest that memory storage in the brain may not be a localized phenomenon at all. Lashley worked with rats, chopping off parts of the rat brain to see if the rat is still able to perform its learned functions such as finding the right direction to turn in a Y-maze in order to find food or avoid a punishment. Strangely, Lashley discovered that sometimes even with 50% of the brain cut off, a rat is able to solve its problem. So memory must be stored "everywhere."

Lashley's student Karl Pribram has used the hologram in order to make a plausible model for understanding Lashley's data. If memory is stored holographically, in the fre-

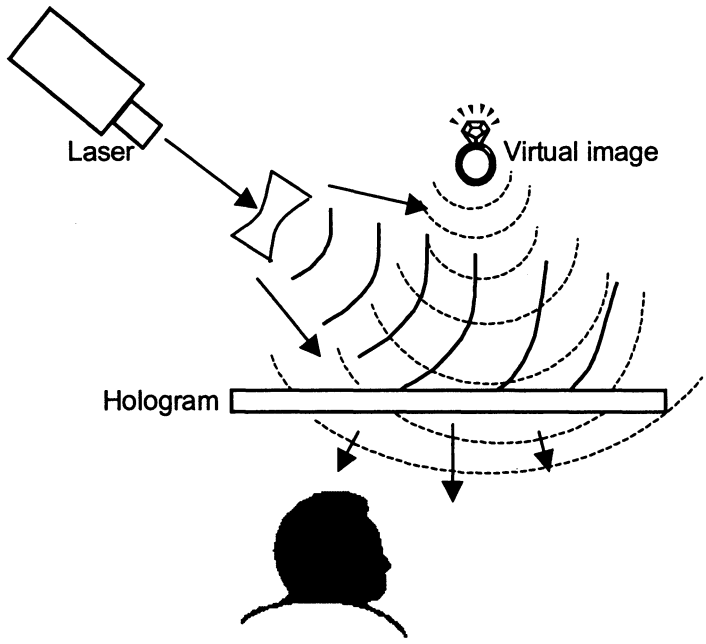

Figure 9.13
Viewing a holographic image.

quency domain, then even a small part of the brain would contain the whole information, and chopping off parts of the brain would not drastically affect the memory. This is the general idea. The model is controversial because it is hard to see how a holographic memory is produced in the brain.

Pribram, and others with him, has even theorized that consciousness itself may be holographic. Then it is easy to understand why we are able to retain some of the memory of the whole (as in spiritual "oneness experiences") even though we are only a minuscule part. Unfortunately, such models are not all too convincing because if we conceptualize consciousness as an object, then it becomes a "hard problem" (to quote the philosopher David Chalmers) to understand our subjectivity, the indisputable subject-pole of an experience.

Bibliography

*"The Tuning Fork," by Louise McNeill, in *The Christian Science Monitor*, July 25, 1977.

CHAPTER 10

Atoms and Chemistry

One of the biggest puzzles of 19th-century chemistry was a piece of work by a Russian chemist named Dmitri Mendeleev, who found some strange but systematic repeated behavior among the elements that he arranged in a table called the periodic table of elements. The periodic table is shown in Figure 10.1. The table exhibits a spectacular periodicity (or repetition) of the properties of atomic elements when arranged in order of increasing atomic number, which is the number of electrons in the neutral atom. All elements having similar properties are put in the same column. The rows of the table define the periods. Thus, the first period has two elements, the second and third have eight, the fourth and fifth have 18, and the sixth has 32. It is believed that the seventh period is not complete. This is due to the fact that the atomic nuclei of elements heavier than 92 are increasingly unstable, so much so that it is increasingly difficult for nature to produce them.

If you are interested in numerology, you can notice one interesting thing about these numbers right away. If you divide each number by 2, you get 1, 4, 4, 9, 9, and 16. These are the squares of the first four integers, 1, 2, 3, and 4.

Ancient Greeks used to be interested in such numerology. In particular, the philosophers led by Pythagoras were fascinated by numbers. Pythagoras discovered the musical octave and knew that other musical harmony is based on small integers. It was but one step more for him to suggest that the motion of the entire world system should be based on numbers. This numerological approach does not work, not as a world system in the macroworld of planets and such. But strangely, in the microworld of the atoms, the Pythagorean idea of the importance of certain discrete numbers seems to have validity.

A. Goswami, *The Physicists' View of Nature*
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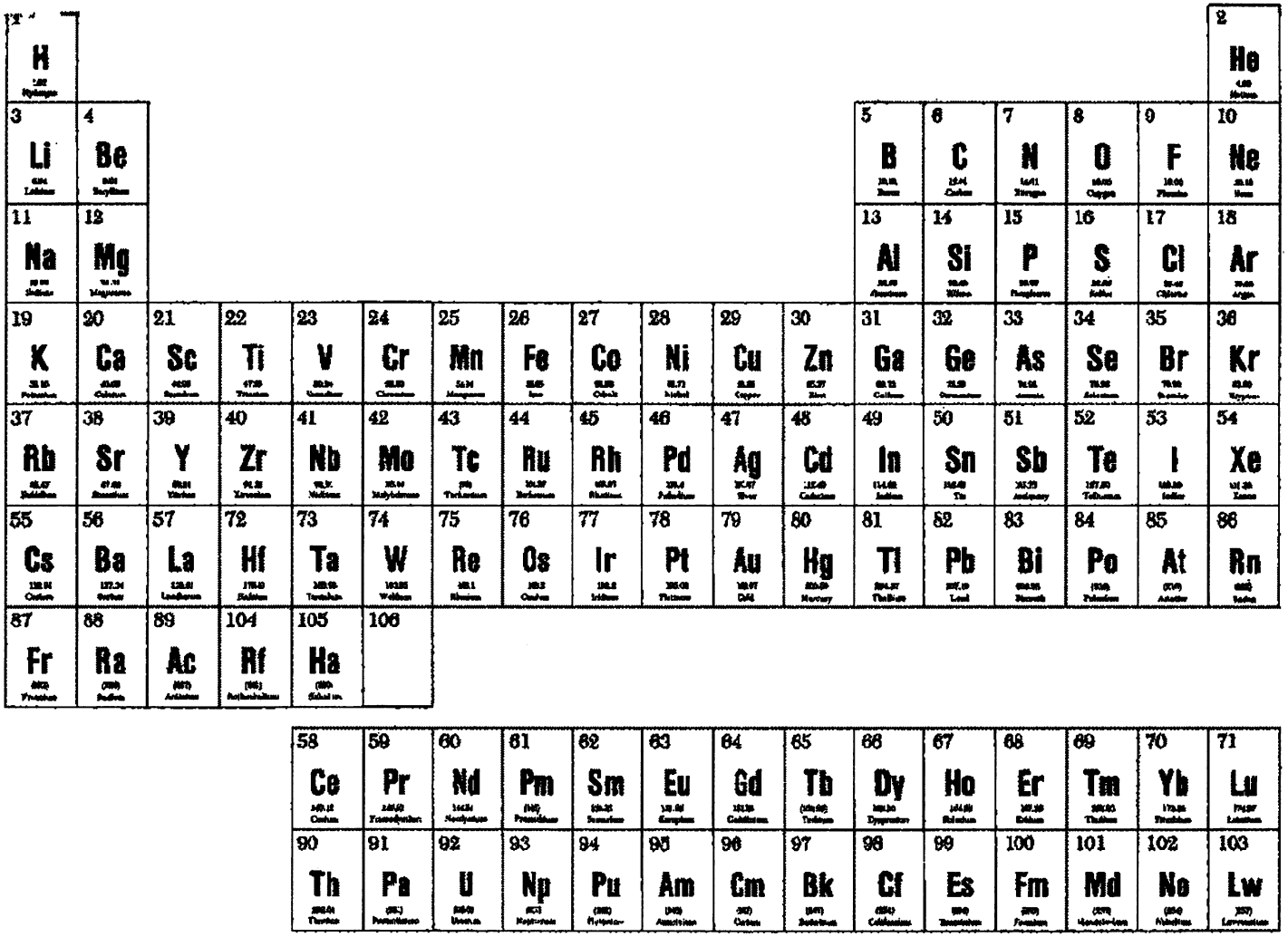

Figure 10.1
The periodic table of elements.

The Quantum Explanation of the Periodic Table

One of the most important achievements of quantum physics was the explanation of the periodic table. The explanation is based on a modern revival of Pythagorean numerology.

The stationary quantum states of the atomic electrons are characterized by a set of four numbers, which we call the quantum numbers. The first of these, called the principal quantum number, takes on the successive values of the integers starting with 1 (i.e., 1, 2, 3, 4, and so forth). It is usually designated by the letter n and is really a measure of the discrete value of the electron's energy in the relevant stationary state. $n = 1$ is the lowest stationary state, or the ground state, $n = 2$ is next, and so forth. The quantum number n also indicates the average distance of the electron from the nucleus; the larger n is, the larger is the average distance of the electron from the atomic nucleus.

For each value of n, a second quantum number, l, can be assigned, which takes on the values starting from zero and going all the way to $n - 1$. Thus for $n = 5$, l can assume values 0, 1, 2, 3, and 4. For multi-electron atoms, the states corresponding to the same n but different l have different energy. The quantum number l actually measures the discrete value of the angular momentum of the electron associated with its motion around the nucleus. The third quantum number, designated by the letter m_l, denotes the direction of the angular momentum vector. It takes on the value from $-l$ all the way to $+l$, increasing in steps of 1. Thus, for $l = 3$, m_l can be -3, -2, -1, 0, +1, +2, and +3. The quantum states that have the same value of n and l but different values of m_l are found to have the same energy, a situation often referred to by saying that these states are degenerate.

The final quantum number, m_s, represents a two-valuedness (m_s can be only $+^1/_2$ or $-^1/_2$) the electron acquires that is unique to some particles in the quantum world. What this means is that for each state characterized by a unique set of n, l, and m_l, the electron has two degenerate states represented by another quantum number m_s, which takes on two values. We often express this by saying that in one state the electron's spin is "up" and in the other state the electron's spin is "down." This designation implies that the electron has a spinning motion about its own axis. This is true in some sense, but the spinning motion of a quantum particle is something very special, certainly not like the spinning motion of daily rotation of the earth around its axis. So it is better to think that the electron has this extra quantum number taking on two values $+^1/_2$ and $-^1/_2$ for each state with a designated n, l, and m_l.

For each value of n, when we add up all the possible values that l, m_l, and m_s can take, we get $2n^2$ individual quantum states, some of them having the same energy. Now recall that the periods also are given as $2n^2$. This must be something more than a coincidence.

It was German physicist Wolfgang Pauli who proposed that only one electron can occupy a single quantum state characterized by the four numbers—n, l, m_l, and m_s—which we have mentioned. This is called the *Pauli exclusion principle*, exclusion because the occupation of one quantum state by an electron excludes any other from occupying it. The atomic electrons obey the rules of a game of musical chairs: they do not sit on each other's laps, never occupy the same position in space; only one electron per chair is allowed, so to speak.

So the first period is explained simply by realizing that for $n = 1$, we have only two

quantum states [$2n^2 = 2(1)^2 = 2$]. If we have only one electron, then that electron will occupy only one of the states. But if there is a second electron, it will take up the second state. And we have both states belonging to $n = 1$ occupied.

Such a configuration is especially stable, the reason being that the energy of the quantum states of $n = 2$ and higher is much larger than that of $n = 1$. This is an extremely interesting fact of the electronic energy levels: the levels cluster in energy around some values. This is called shell structure. There are large "energy gaps" between the shells (Figure 10.2).

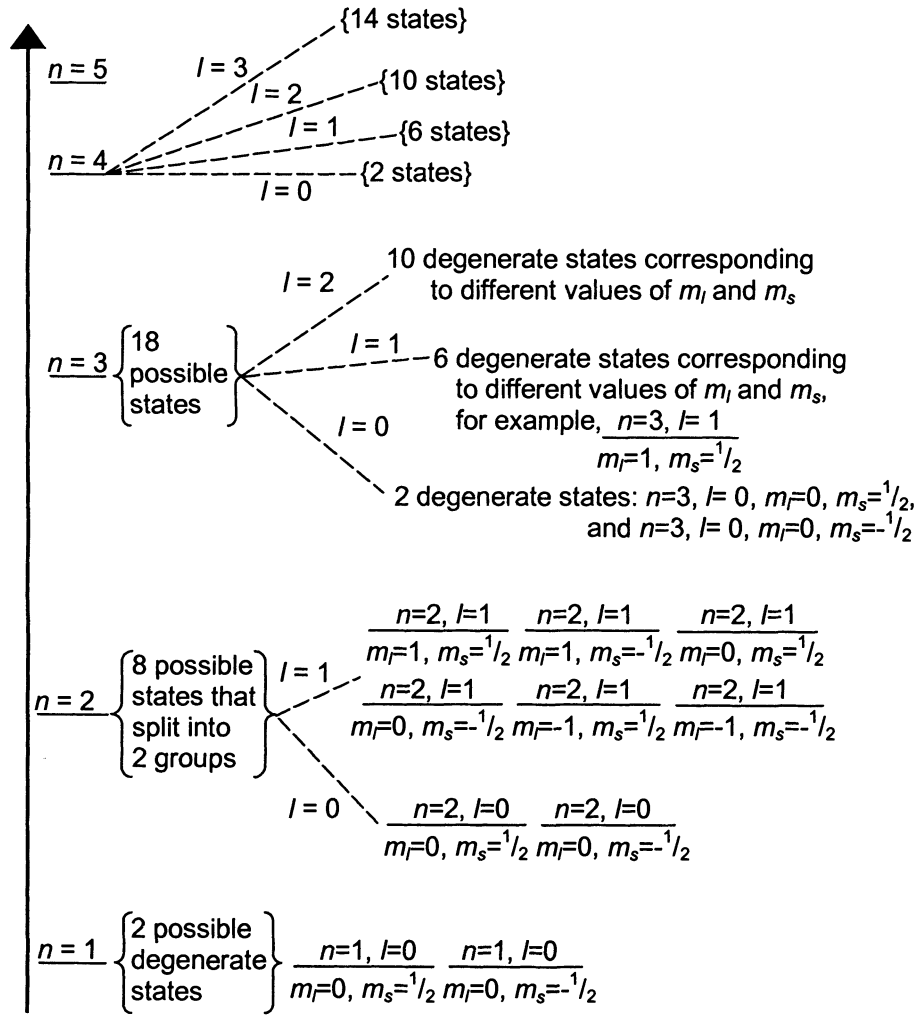

Figure 10.2
The energy states of the electron in a multielectron atom. Each state is characterized by different values of the four quantum numbers n, l, m_l, and m_s. The first three quantum numbers can take only integer values; the fourth can be only $+^1/_2$ or $-^1/_2$. Some of the states have the same energy; they are called degenerate. Notice the large "energy gap" separation between groups of levels of similar energy. This is called a "shell structure."

Let's now assert that for a multi-electronic atom, its electrons must be placed in the electronic states of lowest available energy. This assertion makes sense since we are constructing the state of lowest energy for the atom, its "ground" state. When an atom has just the right number of electrons to fill up the complete shell, the atom is particularly stable indicating the closure of a period. This is the case with helium, neon, argon, krypton, xenon, and radon; they are all noble gases, very non-interacting (see Figure 10.3 for an example).

We can characterize the atom, then, by the number of electrons it has outside the closed shells, since the closed-shell electrons do not take part in chemical reactions. These extra electrons outside the closed shells are called valence electrons. Atoms that have the same number of valence electrons are put in the same column of the periodic table and have similar chemical properties. For example, the "alkali" metals—lithium, sodium, potassium, cesium, and so on—all have one electron outside the closed-shell atomic configuration of helium, neon, argon, and krypton, respectively (see Figure 10.4 for an example). And it has been known for a long time that these metals have similar chemical properties.

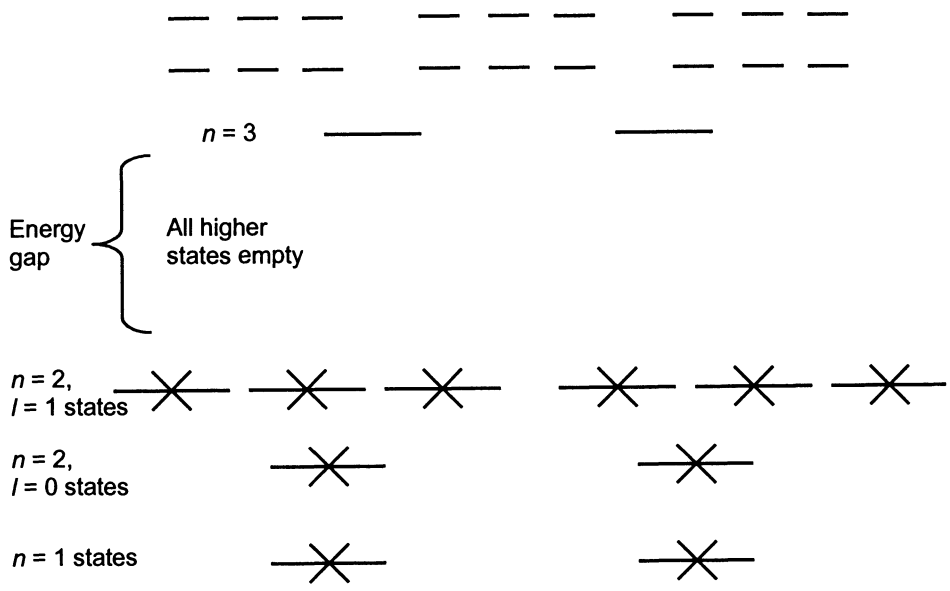

Figure 10.3
The electronic configuration of the neon (Ne) atom. All states of principal quantum number n equaling 1 and 2 are filled (as indicted by the x's). The next available state is separated from the ones shown by an energy gap, which means that it takes a substantial amoung of energy to excite an electron to a higher energy state. This is the reason that neon and other "closed shell" atoms are so stable.

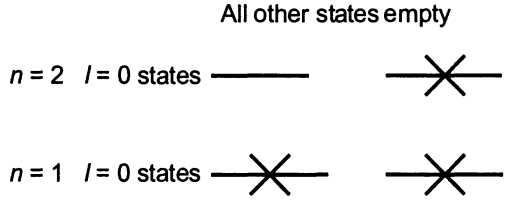

Figure 10.4
The electronic configuration of lithium (Li). It has one electron outside the closed-shell configuration of helium. The electron in the open shell can easily jump into another state without needing much energy.

Since the closed shells are very stable structures, it is understandable that in chemical reactions atoms that get together will try to make closed shells with each other's help. An atom like chlorine (Cl), which lacks one electron from a closed shell, has a particular affinity for an atom that has just the right excess of electrons, such as sodium (Na). Together they make up for each other's lack of closed-shellness. The compound sodium chloride (NaCl), which is common table salt, is the result. As the sodium atom donates an electron to the chlorine, it becomes a positive ion, whereas the chlorine atom becomes a negative ion. The molecule NaCl is held together by the electrical attraction of the two ions (Figure 10.5). Such a chemical bond in a molecule is called an ionic bond. There is also a tight bond when two atoms "share" a few of their electrons to achieve closed-shellness. This is the covalent bond. An example is the hydrogen molecule, H_2. By sharing each other's electrons, both hydrogen atoms seem like closed shell atoms (Figure 10.6).

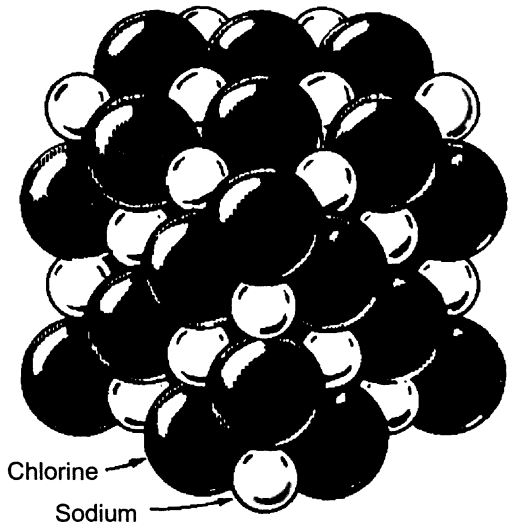

Figure 10.5
The sodium chloride crystal, showing the ionic bond between the sodium and chlorine atoms. The interionic bond between the sodium chloride molecules is large, explaining why molecules with this kind of bonding are ordinarily found in large aggregates like crystals.

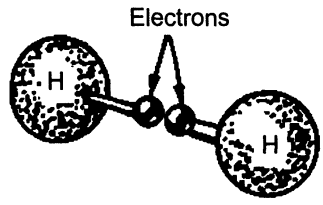

Figure 10.6
The covalent, or electron-sharing, bond. The two hydrogen atoms share their electrons to make the stable molecule H_2. The molecule itself is stable and exists quite independently of others; in fact, the intermolecular force between two hydrogen molecules is small.

Carbon is a very special atom because it combines with a variety of elements, and it can make very large chains of atoms forming very big molecules (see Figure 10.7 for an example). Such "macromolecules" are the essential ingredients of life on earth. The special ability of carbon atoms to form a variety of compounds comes from the fact that their electronic structures are very special. A carbon atom has four valence electrons over the closed-shell configuration of helium. Viewed in another way, it lacks exactly the same four electrons from the closed-shell atom of neon. It turns out that this is almost unique to carbon; only one other element has this property, silicon. This is the reason some people have suggested that if we ever encounter life based on any element other than carbon, that element would be silicon. As you may know, silicon compounds make up our rocks and sands. Can you imagine a rocky creature? Perhaps you have seen the *Star Trek* episode that featured such silicon creatures (imagined, of course).

Pauli Principle in the Stars

We will finish this chapter with an astrophysical application of the Pauli exclusion principle that may interest you. In ordinary stars like our sun, gravity pulls all the matter inwards, but what prevents the collapse of the star under this gravity pressure is the outward thermal pressure exerted by all the gas (Figure 10.8) burning via thermonuclear

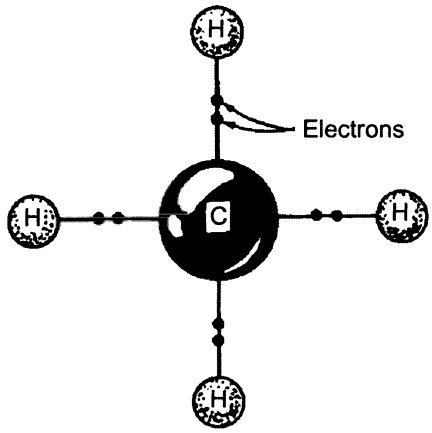

Figure 10.7
The covalent bonding in methane, CH_4, which is also called natural gas.

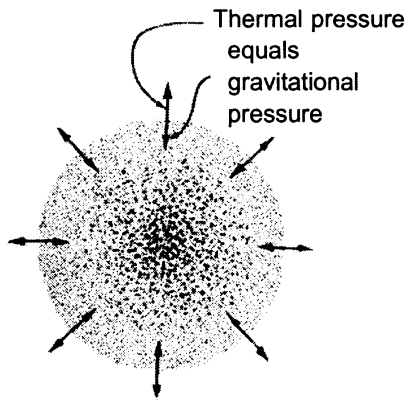

Figure 10.8
A star in equilibrium. The thermal pressure acting outward exactly cancels the inward pressure of gravity, establishing equilibrium.

fusion (as in a hydrogen bomb). But the white dwarf stars are one of the end products of stellar evolution; all the gases have done their burning. What keeps the white dwarf from collapsing then under the enormous gravity pressure?

The explanation for the stability of the white dwarf stage of the evolution of stars comes from the Pauli principle. These stars are in a state in which their atoms are all more or less dissociated into nuclei and electrons. All these electrons make up a gas usually referred to as an electron gas. But in the large sense, all these electrons within the confines of the star define a sort of atom, a giant star-sized atom. As such, they share one very important property of atomic electrons—the Pauli principle.

According to the Pauli principle, no two electrons can occupy the same quantum state or the same space. So in the white dwarf star, since no two electrons can occupy the same position, electrons resist being squished together. The resistive pressure of the electrons against compression is called the Fermi pressure. If the Fermi pressure is just right to balance the inward gravity pressure, we have an equilibrium situation, which is the white dwarf star (Figure 10.9).

The same Fermi pressure explains the equilibrium that exists in neutron stars, which are made up almost entirely of neutrons (neutral particles that also inhabit the atomic nucleus). This time it is the Fermi pressure of neutrons—representing the reluctance of neutrons to share each other's place—that balances the gravity pressure. Neutrons also obey the Pauli principle.

The matter in white dwarf stars exists with a density of some million times that of the sun. The density of the neutron star is even more spectacular—it is 100 trillion times more dense than the sun. Outside of black holes, the neutron star matter is the densest matter encountered in the universe.

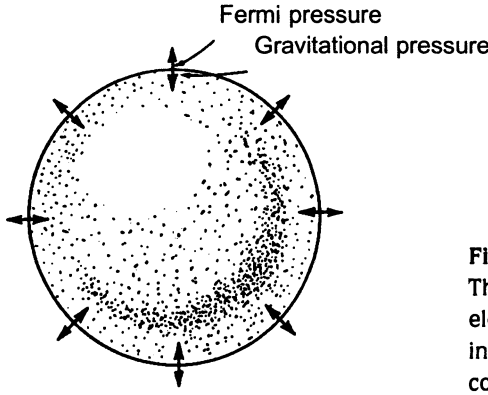

Figure 10.9
The equilibrium of a white dwarf star. The electron Fermi pressure cancels the inward pressure of gravity and prevents collapse of the star.

CHAPTER 11

The World of Nuclei

The nuclear story began with the discovery of the phenomenon of radioactivity, although nobody saw radioactivity as part of "nuclear" physics those days. It continued to unfold with the coming of the 20th century with the discovery of the nucleus by Ernest Rutherford. It stayed dormant for a while during a glorious period of physics that saw the rise of quantum mechanics and the explanation of the structure of atoms. It was revived in the 1930s and enjoyed a spectacular period of startling, epoch-making experimental discoveries followed by very successful application of quantum physics toward the explanation of nuclear structure. Toward the end of World War II, a controversy was stirred by the development of the atomic bomb. The controversy has continued although, at least in part, nuclear technology has shifted to peaceful uses, namely, generation of power in an energy-hungry world. But peaceful uses may have their own perils, and thus the debate continues.

A chance discovery by French physicist Henri Becquerel marked the very beginning of nuclear physics. Becquerel discovered that compounds of uranium emitted strange invisible radiation, strange because he could not do a thing to change the behavior or emission of this radiation. It just kept right on.

Of course, this was 1896, and physicists at the time were pretty much convinced that radiation that represented energy could not be created from nothing. Where was it coming from? Could it be from the uranium atom itself?

The phenomenon was called radioactivity. Uranium and another naturally occurring element, thorium, were found to be radioactive. Were there other elements that shared

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this strange property of uranium and thorium? The famous Curies, Marie and her husband Pierre, discovered two more—radium and polonium—and another gaseous element called radon was discovered among the residue of radium and was found to be radioactive. Soon it was established that all these radioactive elements actually form sequences: parent, child, grandchild, and so on—a sort of dynasty. Radioactivity is a kind of atomic transmutation; by emitting the radiation, uranium becomes other elements (Figure 11.1).

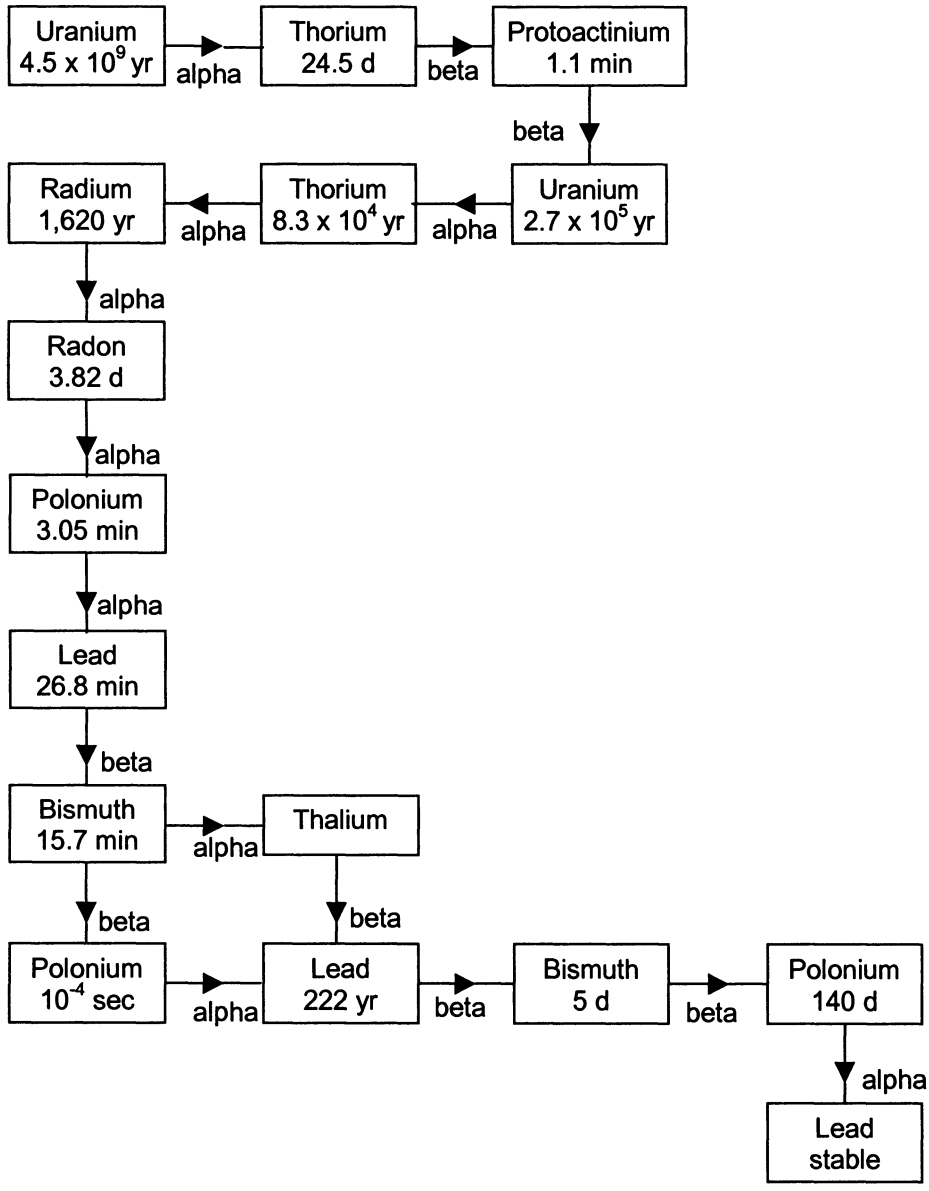

Figure 11.1
By emitting radiation, uranium becomes other elements. The number underneath the name of each element denotes its half-life.

Meanwhile, a New Zealand physicist, Ernest Rutherford, who subsequently settled in England, proved a very important thing. He showed that the radiation from radioactive elements really consists of three different kinds of radiation. The nature of these radiations was to be clarified later, so Rutherford tentatively named them alpha, beta, and gamma rays.

Soon it was established that the alpha rays are really doubly ionized helium atoms, the beta rays are electrons, and the gamma rays are high-frequency electromagnetic radiation (Figure 11.2). The alpha particle has two electronic units of positive charge and a mass about four times that of the hydrogen atom.

The next question about the atomic nucleus was this: What are its constituents? The proton, the nucleus of the hydrogen atom, is the first constituent (the word "proton" originates from the Greek word meaning first). The protons carry positive charge and are responsible for all the charge of the nucleus. However, they alone cannot account for the nuclear mass of nuclei heavier than hydrogen. So Rutherford suspected that there must be a neutral component of the atomic nucleus. This neutral component, called the neutron, was finally discovered in 1932 by another English physicist, James Chadwick. Now nuclear physics was on its way.

There are many reasons for regarding Chadwick's discovery of the neutron as the turning point: it focused the attention of physicists away from the atom and onto the nucleus. But that is only part of the story. The use of neutrons as projectiles to study nuclei and, in fact, transform them, was thought of almost immediately. As a result, two of the most far-reaching discoveries in the field were made. The first was the production of new radioactive substances in the laboratory by the French physicist couple Irene Curie and Fredric Joliot, and the second was the discovery of nuclear fission.

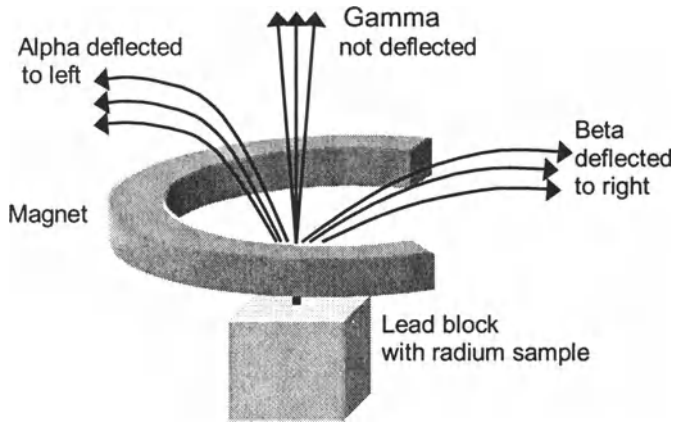

Figure 11.2
Alpha rays are really doubly ionized atoms, and beta rays are electrons; both are deflected by a magnet, but in opposite directions. Gamma rays are not deflected by a magnet, and are high-frequency electromagnetic radiation.

An atom is characterized by the number of protons in its nucleus, which is the same as the number of electrons in the neutral atom. This is called the *atomic number*, Z, sometimes called the proton number. Since the nucleus also contains the neutrons, it is obviously important to keep track of the number of neutrons as well. This is done by a statement of the total number of neutrons plus protons inside the nucleus, a number called the *mass number*, designated by A. The number of neutrons in the nucleus is then $A - Z$, and this is called the *neutron number* N of the nucleus.

It was known for some time that the same element could exist in forms having somewhat different atomic weights. Such forms were called *isotopes* of each other. The isotopes now found a natural explanation with the realization that two isotopes of the same element had the same number of protons inside their atomic nuclei but a different number of neutrons. The atomic or chemical properties of two isotopes are practically the same, having the same number of electrons in the neutral atomic state. But the different number of neutrons suggested that their nuclei were different, and therefore they could have different nuclear properties. Figure 11.3 shows three different isotopes of hydrogen–hydrogen, deuterium or heavy hydrogen, and tritium. Indeed, the nuclear properties of the three isotopes are quite different; for example, tritium is radioactive while the other two are not.

The most spectacular demonstration of how nuclear property changes with the addition of neutrons was the discovery of radioactive isotopes of naturally occurring stable elements produced in the laboratory with the help of nuclear reactions. Clearly, radioactivity also had to be a property of the atomic nucleus, a transmutation of the nucleus with the emission of radiation.

The existence of isotopes also makes it imperative that when referring to an atomic nucleus, we not only use the chemical symbol but also the mass number. For example, ^{14}C or ^{235}U. The superscript on the left of the symbol denotes the mass number.

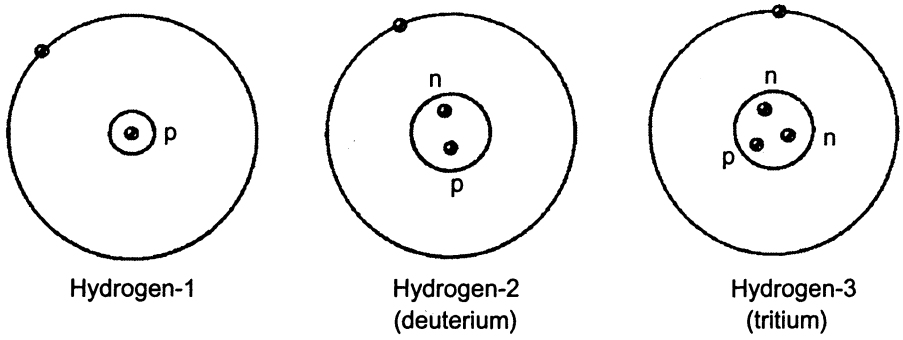

Figure 11.3
Three isotopes of hydrogen. They belong to the same element, having the same number of protons and electrons and the same chemistry, which depends only on the electronic structure. But the nuclei of the isotopes contain different numbers of neutrons. The hydrogen-1 nucleus is just a proton (p) with no neutrons. The hydrogen-2 (deuterium or heavy hydrogen) nucleus contains a proton and a neutron (n). And the hydrogen-3 (tritium) nucleus has a proton and two neutrons.

Nuclear Stability

Radioactivity is the process by which unstable nuclei emit radiation of different varieties. Often in the process the nuclear species themselves undergo transmutations (e.g., alpha and beta decay). Sometimes the nucleus just de-excites from an excited energy level to another, lower energy level, giving off gamma radiation in the process (gamma decay).

Let's answer a few questions. Why are some nuclei unstable against radioactive decay while others are not? A decaying nucleus must be characterized by a rate of decay. In other words, we can ask, "How long does it take a given radioactive sample to decay away so that no further activity is left?"

There are several and sometimes conflicting tendencies of nuclear interactions that determine the stability of nuclei. First of all, two protons, in addition to their attractive nuclear interaction, have the repulsive electrical interaction to reckon with. When there are a large number of protons and each feels the repulsion due to the other protons, the magnitude of the repulsion starts to be competitive with that of the nuclear attraction. Since repulsive forces tend to take the protons apart from the nucleus, a large number of protons do not contribute to stability. This is why heavy, stable nuclei are usually found to contain a hefty excess of neutrons. Since neutrons only attract (via the nuclear force), a neutron excess gives adequate "glue" in the stabilization process.

But we may wonder why nuclei are not just bundles of neutrons alone. Why have the proton at all with its problem of electrical repulsion? The answer is that the attractive force between neutrons and protons is the strongest (stronger than the nuclear attraction between a pair of protons and a pair of neutrons). Because of this, there is a tendency for nuclei to have an equal number of protons and neutrons. The nuclei we find in the universe occur as a result of the competition between these two tendencies: (1) to avoid having a large number of protons, and (2) to have an equal number of protons and neutrons. Thus, we get the chart shown in Figure 11.4.

Let's discuss the chart, which is a plot of the proton number Z of the nucleus against the neutron number N. The stability region is shown by the boxes in the figure. Unstable nuclei that decay by alpha emission are shown by X's. Notice that alpha instability occurs only for heavy nuclei.

In Figure 11.4, below the region of stability we are dealing with unstable nuclei that have too many neutrons relative to what is optimal for stability. These nuclei tend to decay by (beta) emission of electrons. The basic process contributing to the decay is the beta decay of the neutron converting itself to a proton:

$$n \rightarrow p + e + \bar{\nu}$$

where n denotes a neutron, e an electron, p a proton, and $\bar{\nu}$ an antineutrino. The child nucleus from such a decay has one more proton and one less neutron than its parent, and is therefore relatively more stable. An example is the beta decay of strontium (^{90}Sr) into yttrium (^{90}Y):

$$^{90}\mathrm{Sr} \rightarrow {}^{90}\mathrm{Y} + e + \bar{\nu}.$$

Likewise, nuclei lying above the region of stability are unstable because they contain too many protons. These nuclei therefore exhibit positron beta (β^+) decay (a positron is a positive electron—an electron's "anti-particle"). The basic process here is the conversion of a proton into a positron, a neutron, and a neutrino:

$$p \rightarrow n + e^+ + \nu.$$

An example of this kind of decay is that of cobalt ^{56}Co into iron ^{56}Fe:

$$^{56}\text{Co} \rightarrow {}^{56}\text{Fe} + e^+ + \nu.$$

It is extremely important to note that, whereas a free neutron does show the beta decay process, a free proton never decays: it is stable. Only a proton inside a nucleus can undergo the positron decay process.

Nuclei in Figure 11.4 that lie far below the stability region are unstable against neutron emission. Such nuclei decay very fast, and therefore are difficult to produce even for a very short time in the laboratory. Nevertheless, such nuclei are sometimes encountered in nuclear fallout or similar situations. The nuclei far above the stability region are unstable against proton emission, and the same comments apply to them.

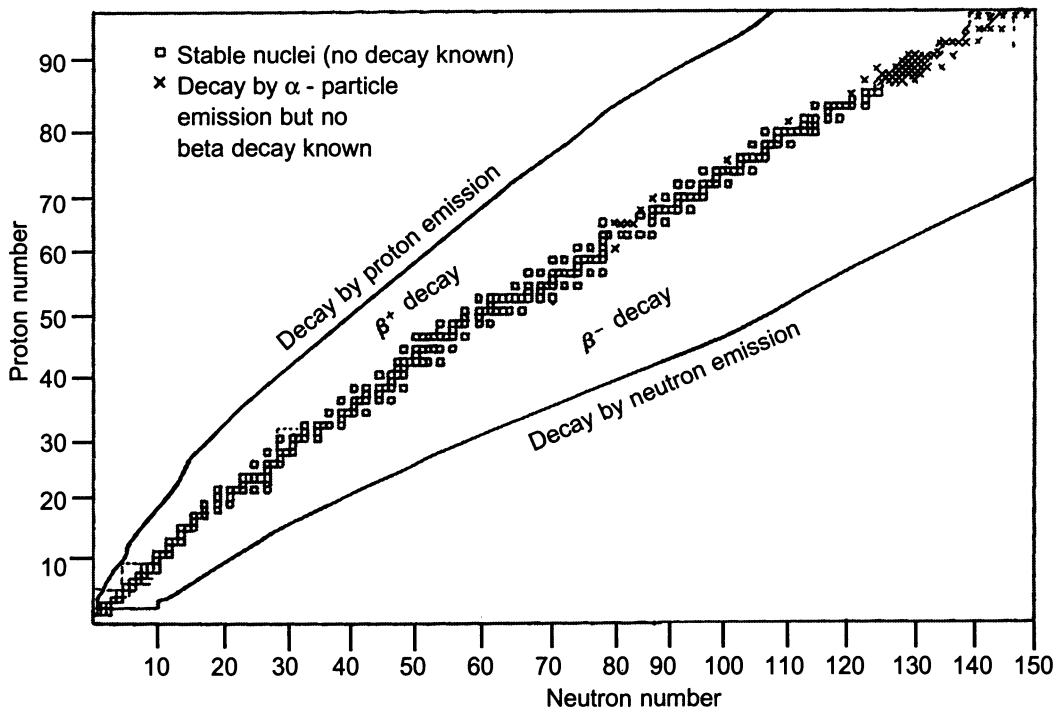

Figure 11.4
Plot of number of protons versus number of neutrons for all possible nuclei, showing stable nuclei and showing how unstable nuclei decay. (Excerpted from *Nuclear Science and Society*, by Bernard L. Cohen. Copyright 1974 by Bernard L. Cohen. Reprinted by permission of Doubleday & Company, Inc.)

Nuclei with a Z significantly greater than 92 often decay by fission or the breaking up in fragments of smaller nuclei, spontaneously. The nuclei that result from the fission of the heavier nucleus are usually radioactive, and neutrons are emitted in the fission process itself. So spontaneous fission is also often classified as a radioactive decay.

Nuclear Fission

The discovery story of *nuclear fission* is both interesting and dramatic. It started in 1935 with the Italian-born American physicist Enrico Fermi, in Italy at the time, who had the idea to produce transuranic elements (elements beyond uranium in Z number) by bombarding uranium with slow neutrons. The term "slow neutron" may be confusing; how slow is slow? Slow means roughly having energy comparable to that of a molecule at room temperature. Fermi and his collaborators did their experiment and found something new, but they misinterpreted the results, thinking they had discovered transuranic material. Actually, what they had seen was the breakup of an isotope of uranium of mass number 235 into two lighter nuclei, a process now called fission (Figure 11.5).

The mistake was not cleared up until later by two German chemists Otto Hahn and Fritz Strassmann. Being chemists, they were able to separate and identify the products of uranium bombardment with slow neutrons. Soon afterwards physicist Lise Meitner and her nephew, Otto Frisch, suggested that tremendous energy must be liberated in the fission process.

Meanwhile, Fermi had moved to America in order to avoid the Fascist regime of Mussolini in Italy. The news of the work of Hahn and Strassmann and of the suggestion of Meitner and Frisch reached him through the mouth of no other than Niels Bohr. Within 24 exciting hours, the newspapers were reporting the verification of the energy aspect of nuclear fission. Indeed, tremendous energy comes out when a uranium nucleus divides into two. A truly Promethean discovery.

The energy released in uranium fission was soon to be used in the atomic bomb. The fission process was also harnessed as a source of electricity. The nuclear power plants of today are all based on fission power.

But fission power is controversial, the elements of the controversy can be seen in the following two contrasting quotes:

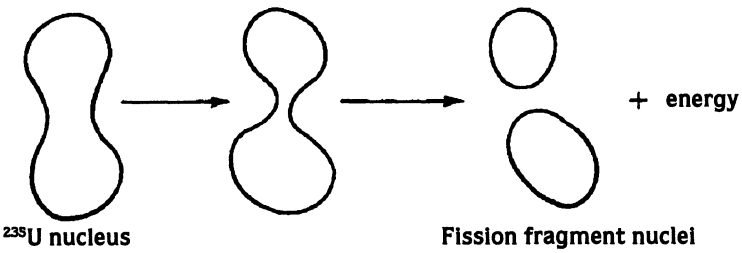

Figure 11.5
The fission of a uranium nucleus. Energy is released.

> I am an advocate of nuclear energy. I believe that the technology of nuclear power reactors offers great benefits to mankind, without commensurate costs, and that we can reduce (and have reduced) the risks associated with it to an acceptable, and indeed very low level. —Bernard I. Spinrad, nuclear physicist, Oregon State University

> Fission energy is safe only if a number of critical devices work as they should, if a number of people in key positions follow all their instructions, if there is no sabotage, no hijacking of transports, if no reactor fuel processing plant or waste repository anywhere in the world is situated in a region of riots or guerilla activity, and no revolution or war—even a "conventional one"—takes place in these regions.
>
> —Hannes Alfven, Nobel laureate physicist

Another major discovery of nuclear physics in the 1930s was that ***thermonuclear fusion reactions***, fusion or joining together of light nuclei into heavier ones, is responsible for the heat generation in stars. The same energy is used in the hydrogen bomb, and today research continues to develop peaceful uses of nuclear fusion as in power plants (so far without success).

Nuclear Structure

The discovery of the neutron paved the path to the beginning of a theoretical understanding of nuclear physics. Since nuclei were now perceived clearly as tight packets of neutrons and protons, the theorists became busy in their attempt to understand the force that holds the nucleons together (the word "nucleon" refers collectively to both the neutron and the proton, the inhabitants of the nucleus). The nuclear force was found to be the strongest of all known forces, but restricted to a very short region of space not extending beyond the boundaries of the nucleus itself. Strong, attractive, and short range: these are the characteristics of the forces that bind the nucleons. And only nucleons and a family of particles that we call ***hadrons*** possess this special strong way of interacting. Other particles—electrons, for example—do not interact with this force.

The properties of nuclear force are very different from the two other fundamental forces that you are familiar with: electromagnetic and gravitational. These two forces are of infinite range. The short range of the nuclear force is an essential ingredient of nature's order, because if such a strong force were longer range, it certainly would have disturbing effects on things such as chemical bonds, molecular structure and so on. We have no idea how nature would have adjusted to that.

The same short range, however, prevents our using nuclear force on the macroscopic scale. Because of their long range, both electromagnetism and gravity allow for superposition. We can add little charges together and get a big effect for their sum. The same goes for masses, of course. No such thing exists for nuclear force. Because of the short range, the forces of an assembly of nucleons do not add up as they do for charges. So we cannot make large macroscopic-sized nuclear objects that would attract other nuclear objects outside the nuclear distances with a huge force.

Now we come to a very important idea. So far we have talked about the nuclear force of the nucleons. This is their binding force, and it is by far the most important force in

their interaction. However, they also have other interactions. The proton has electrical interactions with other charged protons and other charged particles by virtue of their electrical charges. Actually, the electrical interactions of protons play quite a significant role in nuclear dynamics, as we saw in the alpha particle scattering experiment described earlier (see Chapter 5). The positively charged alphas are repelled electrically by the positive charge of the nuclear protons. The weak interaction of nucleons is responsible for radioactivity with beta emission. The nucleons also have gravitational interaction by virtue of their masses, but gravity is just too small to have any significant effects, and we ignore it when talking about nucleons and nuclei.

The nuclear physicists don't stop here. They are particularly interested in the associations of the nucleons inside the nuclei—how they cooperate, what rules determine the greater stability of some nuclei over others, the structure of the average distribution of nucleons inside their residence, the rules of their reactions and scattering when two nuclei hit each other or a nucleus is hit by a nucleon or some other projectile, and on and on goes the list.

The strangest thing that emerges in the theorist's picture is the fact that inside the nucleus the nucleons behave as basically independent objects, although bound inside the overall nuclear box. This is surprising, because nucleons are such strongly interacting objects that we would expect them to interact violently with one another all the time. Instead, they seem to settle down in a relatively ho-hum existence. One consequence is that the energy levels of nucleons inside nuclei also exhibit a shell structure like the atomic energy levels of the electron. Nuclei with filled shells are especially stable and are called "magic nuclei." This independent particle picture is usually called the *nuclear shell model.*

Within the shell model, nucleons seem to have some weaker, residual interactions among themselves, which give rise to additional interesting cooperative phenomena. For example, if the independent particle picture were totally true, all nuclei would have spherical shape (Figure 11.6). The nucleons would distribute themselves in the nuclear well in a spherically symmetric manner. This turns out to be not true. Because of the residual interactions, the nucleons often manage to distribute themselves in the shape of an ellipsoid

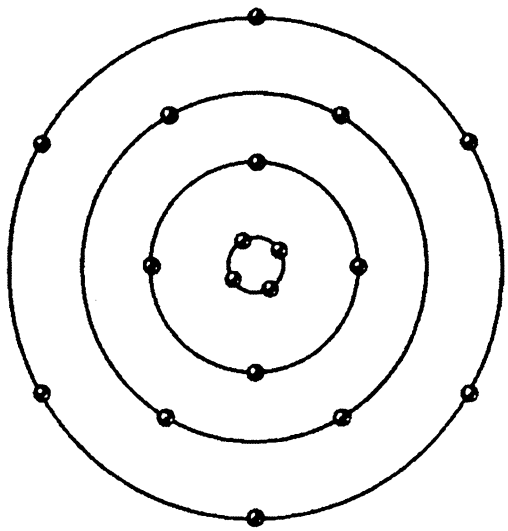

Figure 11.6
A spherical nucleus. The nucleons are distributed in a spherically symmetric way.

(such as a football); such nuclei are called deformed (Figure 11.7). And there are nuclei that have shapes somewhat intermediate; their deformation is kind of "soft." But now we are really getting into the intimate workings of nuclear theory.

Are you beginning to get the picture? Admittedly these things are hopelessly remote from your reality. There is a story about a physicist who actually calculated the distribution of the nucleons inside a nucleus of deformed shape (Figure 11.8). He was rightly very

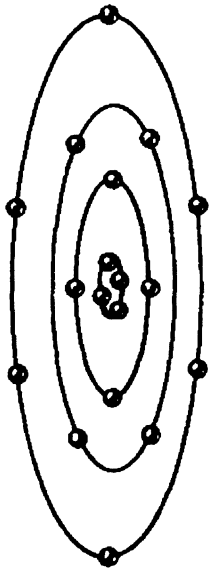

Figure 11.7
A deformed nucleus. The nucleons are distributed in an ellipsoidally symmetric way.

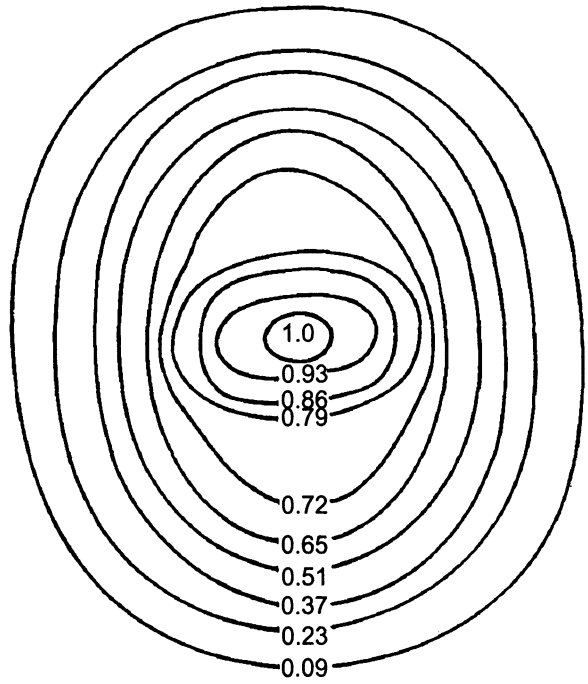

Figure 11.8
The detailed shape of a deformed nucleus. The lines join points of equal density of the nucleons inside the nucleus. The numbers are relative to the central density, which is assumed to be 1. (From A.L. Goodman, et al., *Physical Review C*, vol. 2 [1970], p. 380.)

excited. When he came home from work, he took this drawing out of his briefcase and said to his wife, "I finally know what the distribution of nucleons inside a complicated nucleus really looks like." She took the picture, looked at it for a second, and said, "You are out of your mind."

Nevertheless, the models of the theoretical nuclear physicist and their experimental study are important because of the predictive power of these models. As an example, one of the models has predicted the existence of long-lived super-heavy nuclei with a Z of around 114. Such super-heavy nuclei could influence nuclear technology in a radical manner, and they are searched for by physicists as one of their priority items. One project for this kind of investigation is called heavy ion collision—large ionized atoms like uranium are accelerated and allowed to collide with other large, ionized atoms to see if any super-heavy nuclei come out.

Nucleons are made of elementary particles called quarks (see Chapter 12), and more recently the study of nuclear structure has shifted toward finding the effect of quark structure of nucleons in nuclei.

An Application of Nuclear Physics: A Revolution in Geology and Archeology

One of the amazing things about radioactivity is that it is not affected by any of the usual physical and chemical means, such as heat, cold, pressure, or chemical reaction. The radioactivity of an element stays just the same when it is present in a chemical compound. For example, oxides of uranium are as radioactive as pure uranium. Radioactivity is a nuclear process, and nothing short of nuclear processes can change it. This particular property is unfortunate in many ways—we cannot get rid of radioactive substances easily—but it also is a boon in some instances. For example, because of this nonchangeability, radioactivity gives us a very reliable time clock. We can identify material from ancient times by finding out how much of a particular radioactive nuclear sample is left in the object. This has revolutionized archeology and geology. This field is called *radioactive dating*.

An example of dating that is very useful in archeology is *radiocarbon dating*. Radiocarbon refers to an isotope of carbon (C), ^{14}C. Ordinary carbon is mostly ^{12}C, but trace amounts of radiocarbon are contained in all living objects.

Several things conspire to create the radiocarbon in living objects. The cosmic rays that bombard the earth constantly contain neutrons as one ingredient. These neutrons are energetic enough to initiate a nuclear reaction, involving nitrogen-14 nuclei (of atmospheric nitrogen), that converts them into carbon-14:

$$^{14}N + n \rightarrow {}^{14}C + p.$$

Here n denotes a neutron and p denotes a proton. The radiocarbon atoms produced in this way chemically react with oxygen of the atmosphere, making carbon dioxide. Thus, some of the carbon nuclei in the carbon dioxide in our atmosphere are really radiocarbon, about one part in 10^8. When plants absorb the atmospheric carbon dioxide by photosyn-

thesis, they absorb a trace of the radiocarbon as well. Animals eat plants, and other animals eat animals: as a result every living thing acquires some amount of radiocarbon (Figure 11.9).

In the body of a plant or any other living object, the ^{14}C nuclei continue their radioactive (beta) decay:

$$^{14}C \rightarrow {}^{14}N + e + \bar{\nu}.$$

But the supply is continually replenished by new intakes, so what results is a stable

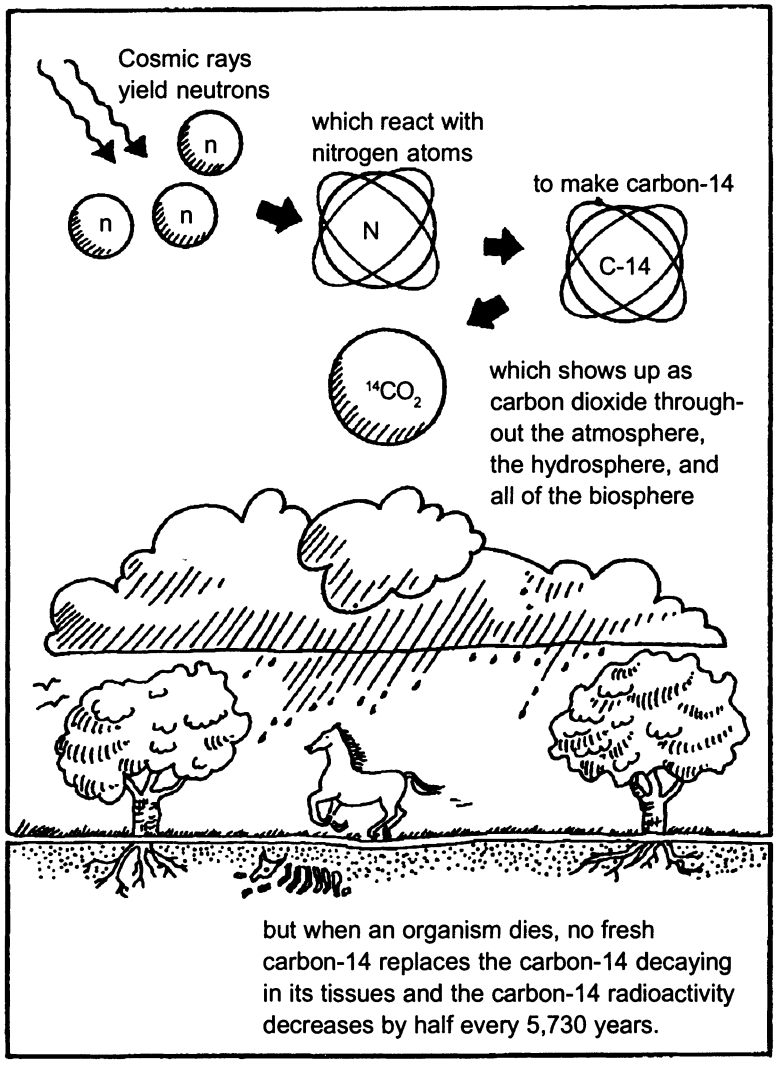

Figure 11.9
How carbon-14 is formed and how it enters into the biosphere. (Courtesy: Energy Research and Development Administration.)

situation, a fixed ratio of radiocarbon nuclei and regular ^{12}C nuclei. Thus all living objects have this property: their carbon atoms include a fixed proportion of radioactive variety. And this is responsible for a fixed amount of radioactivity per unit mass of carbon in a living sample: about 15,000 beta emissions occur every minute for a kilogram of carbon in living tissue.

Once the living object dies, there is no further replenishment of radiocarbon. The radiocarbon nuclei, however, continue to decay, and as a result their proportion to regular carbon nuclei decreases with time for a dead object. The radioactivity of a dead sample will decrease as time goes on.

So if we find a few bones from prehistoric time, or the remnants of a coffin, we can determine the percentage of radiocarbon in the object, which determines how much time has elapsed since the skeleton belonged to a living creature or the wood of the coffin was part of live trees. Since ^{14}C has a half-life of 5,730 years, after 5,730 years the activity will be only 7,500 emissions ($^1/_2$ of 15,000) per minute per kilogram, we will get 3,750 emissions per minute per kilogram after 11,460 years; and so forth. Conversely, if a sample shows 3,750 emissions per minute per kilogram, we know that its age must be about 11,460 years.

How far back in time can we go with radiocarbon dating? Because the number of emissions decreases by a factor of 2 every 5,730 years, after about ten half-lives (that is, about 57,000 years), the activity will have dwindled to just under 15 ($15{,}000/2^{10} = 15{,}000/1{,}024 \approx 15$) emissions per minute per kilogram of carbon. This is pretty close to the limits of experimental accuracy. Although ages as old as 100,000 years have been estimated by this method, the accuracy is questionable.

Thus, radiocarbon dating has its maximum usefulness in the age determination of archeological findings. For most geological dating we have to use other radio nuclei.

The Uranium-Lead Method of Dating

When the first lunar rocks were brought to earth, geologists immediately measured and declared the ages of these samples. The oldest one so far has been found to be some 4.5 billion years old. How can we be so sure?

If you read an article on evolution, geological or biological, you frequently come across time scales of the order of 10^8 years. Even the fastest geological processes occur with a time scale of a million years. How do we determine such old ages?

There are several radioactive dating methods available to the geologist, and usually one of these is more suitable than another in a given situation. In each case we look for the remnants of the decay of a long-lived radioactive isotope; by finding out how much is left we can tell how long the sample has been around.

We will examine one of these techniques, ***uranium-lead dating***. We previously have displayed the decay chain of uranium (Figure 11.1), in which the final child nuclei, the end of the line, are two isotopes of lead, lead-206 and lead-207. Naturally occurring lead is mostly lead-208. So by measuring how much lead-206 or lead-207 is present, we can tell how long the uranium has been around, since we know the half-life of uranium is 4.5 billion years. And there is one more thing that is important. The amount of lead *really* tells us the time that has elapsed after the rock sample settled down to cool. In a hot

environment, like that in the interior of the earth, the lead melts and separates out as it is formed. When cold, however, the lead stays within the sample. Thus the dating tells us exactly the time we want to know: when the rock sample was deposited from the interior to the surface.

CHAPTER 12

Elementary Particle Physics: The Quest for Elementarity

When we look at a forest from a distance, it looks like a unified whole. But as you approach it, you find that it is made up of individual units. The philosophers of ancient Greece found this intriguing. Is it possible, they argued, that matter is also like this? If we look close enough at an object, perhaps its wholeness will disappear and the object will be found to be made up of elementary particles, just as the forest is made up of individual trees. Among the Greek philosophers, the most outspoken proponent of this "atomic" view of matter was Democritus: matter is composed of "indestructible" units called "*atomos*," he said. (As you can guess, the word *atom* originated from this Greek word.)

Now, of course, more than 2,000 years after Democritus, the atomistic constitution of matter is well established. We know that a solid object is not solid, after all; looked at closely, it is seen as a conglomerate of atoms separated by empty space. But the modern atom is not the indestructible elementary constituent of matter that Democritus envisioned; it also has a structure. Not even the atomic nucleus, the core of the atom, is elementary. It also is a conglomerate of other particles called neutrons and protons. Are neutrons and protons elementary in the sense intended by Democritus? Or are there elementary particles from which protons and neutrons are made? How far down the line does one have to go before we find the real elementary particle? This is one of the motivating quests of elementary particle physics.

A. Goswami, *The Physicists' View of Nature*
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Another motivation comes from a desire to understand the nature of the nuclear force, the strong interaction, and forces between subatomic particles in general. Even in quantum physics we know that we really ought to talk about a force field rather than a force. But in the quantum world of subatomic particles, the field itself acquires a graininess. This is the idea of the quantum field—a grainy field rather than a continuous one. The quantum field theory, although by no means a completely understood theory, has added new dimensions to the concept of a force between two particles and to the subject of the interactions.

But before we discuss either of these two topics, let's discuss how we study our subjects (which are so tiny) at a close level. We can think of a light by which to see, such as small-wavelength gamma rays, as small as the size of the proton or smaller. The problem is that these gamma photons have such high energy that they disrupt the particle they hit in a major way, so the result is not unambiguously clear. But this also tells us that it is not necessary to use light alone. We can hit the particles with other projectiles, like protons and electrons, and study the results. To get close to the target subatomic particles, our projectiles must, like the gamma ray, have high energy. Thus, physicists have built machines called particle accelerators that create beams of electrons or protons of extremely high energy. For this reason elementary particle physics is also called *high-energy physics*.

When we hit our particles with these high-energy projectiles, the outcome of the collision is usually a larger collection of particles. But we must not jump to the conclusion that the resulting particles are the constituents of the target particles. This is not true because of a strange aspect of the relativistic equivalence of mass and energy. Whenever sufficient energy is available, some of the energy manifests itself as mass, which takes the form of these particles that come out—of course, subject to all the other laws of physics. For example, the conservation law of the number of baryons, which we discussed earlier, must hold in determining which particles can emerge.

The outcoming particles from a collision event are detected by the tracks they create in a *bubble chamber*, a device containing a liquid that bubbles as a charged particle passes through it. The line of the bubbles gives the track of the particles (Figure 12.1). And the elementary particle physicist tries to find answers in these tracks.

Perhaps you can appreciate the plight of the particle physicist after you've read the following episode from *Winnie-the-Pooh*:

> "Hello!" said Piglet, "what are you doing?"
> "Hunting," said Pooh.
> "Hunting what?"
> "Tracking something," said Winnie-the-Pooh very mysteriously.
> "Tracking what?" said Piglet, coming closer.
> "That's just what I ask myself. I ask myself, what?"
> "What do you think you'll answer?"
> "I shall have to wait until I catch up with it," said Winnie-the-Pooh. "Now there." He pointed to the ground in front of him. "What do you see there?"
> "Tracks," said Piglet. "Pawprints." He gave a little squeak of excitement. "Oh, Pooh! Do you think it's—a—a woozle?"
> "It may be," said Pooh. "Sometimes it is, and sometimes it isn't. You never can tell with pawmarks."

"Wait a moment," said Winnie-the-Pooh, holding up his paw. He sat down and thought, in the most thoughtful way he could think. Then he fitted his paw into one of the tracks . . . and then he scratched his nose twice, and stood up.

"Yes," said Winnie-the-Pooh. "I see it now. I have been Foolish and Deluded," said he, "and I am a Bear of no Brain at All."

"You're the Best Bear in All the World," said Christopher Robin soothingly.

Like Pooh, the particle physicist looks for his "Woozle," the mysterious elementary constituent of nature, if such exists. And like Pooh, he is constantly plagued by the possibility of making a fool of himself, because deciphering these "Woozle" tracks in the bubble chamber is an extremely tricky operation. In spite of this, the knowledge amassed from such collision experiments is amazing.

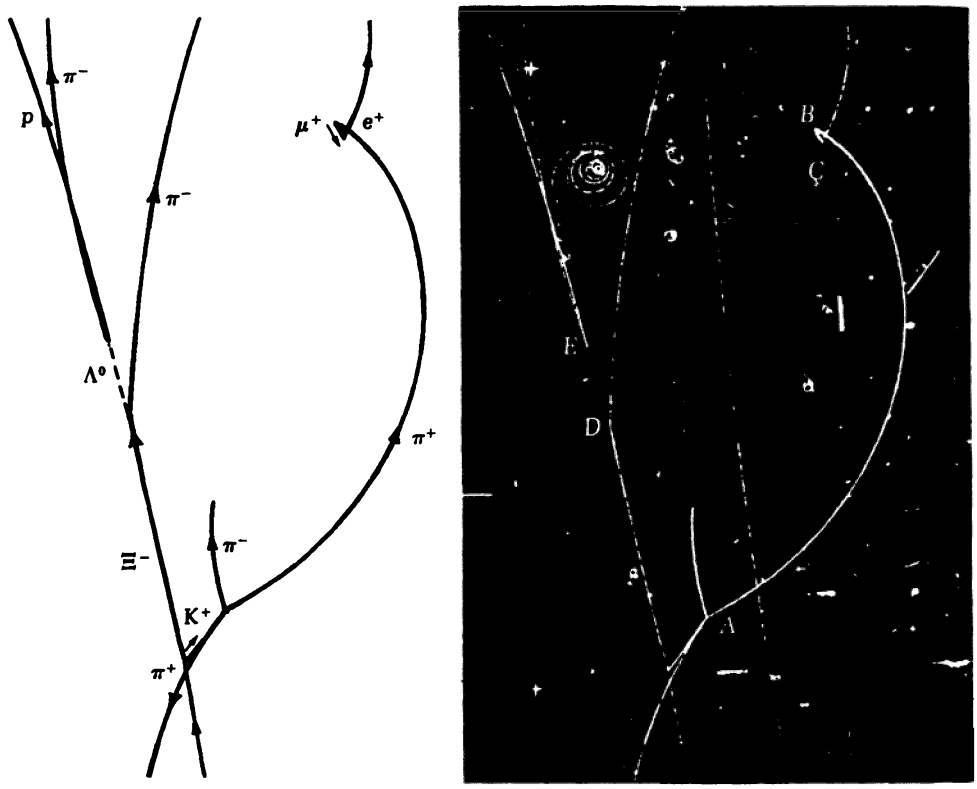

Figure 12.1
A bubble chamber phograph showing the decay of five different subaomic particles. On the right is the actual photograph. At the point marked *A*, a positively charged particle of the meson class called K^+ decays into three pions (π). At the point marked *B*, one of these pions decays into a muon (μ) and an unseen neutrino (which is neutral and does not leave a track in the bubble chamber). At *C* the muon is found to decay into a positron (and two neutrinos). At point *D* a cascade particle (Ξ) decays into a lambda (Λ) particle (which does not leave a track) and a pi meson. Finally, the invisible neutral particle lambda decays into a proton (*p*) and a pion (whose track we can see) at point *E*. On the left is a schematic analysis of the photograph. (Courtesy Lawrence Berkeley Laboratory.)

The Particles and Their Interactions

Experimental particle physicists have discovered with their accelerators and bubble chambers hundreds of subatomic particles. Table 12.1 shows some representative ones. There are so many of them that the designation of "elementary particle" is now considered meaningless for most of them.

The first two decades of particle physics were spent classifying the "zoo" of particles. The result has shed considerable light on the affair. One very broad classification results from consideration of the Pauli exclusion principle: if a particle obeys it, it is called a *fermion*; if it does not, it is called a *boson*. Two fermions cannot occupy the same space at the same time, but two bosons can.

Fermions are further classified into two major groups: *baryons* (meaning heavy) and *leptons* (meaning light). Baryons consist of the proton, neutron, a group of particles under the generic name of *hyperon*, and another group of particles that are considered to be

Table 12.1
A Sampling of Subatomic Particles

Proton	Nucleon	Baryons	Fermions (obey Pauli principle)
Neutron			
Lambda	Hyperons (strange)		
Sigmas			
Cascades			
Omega			
Delta and others	Baryon Resonances (excited states of baryons)		
Electron		Leptons (interact weakly)	
Electron neutrino			
Muon			
Muon neutrino			
Tau			
Tau neutrino			
Pions (π mesons)		Mesons	Bosons (do not obey Pauli principle)
K mesons			
Eta meson and others			
Photon			
W boson			
Z boson			
Graviton* and others			

*not yet discovered

excited states of baryons, called *baryon resonances*. All hyperons are heavier than the nucleons (neutron and proton) and, if in the free state, they always decay into a proton plus some other particles. All baryons interact via both strong and weak nuclear interactions.

The leptons are the group of particles consisting of the electron, the *muon*, and the *tau* (this is a recent addition to the lepton family). They have charge and mass; and then there are three possibly massless (that is, zero rest mass) neutral particles called *neutrinos*. Here is another interesting thing: each lepton seems to be associated with its own brand of neutrino; the number of each lepton plus its neutrino is a conserved quantity. For example, the total number of electrons and electron neutrinos always remains the same in all reactions or particle decay processes. If an electron is emitted in a process (such as in nuclear beta decay of radioactivity), then we know from this that an anti (electron)-neutrino must also be emitted in order that the number of electrons and electron neutrinos remains the same. The emission of the electron increases the number of electrons by one, but the emission of the antineutrino decreases the number of electron neutrinos by one, so the total number of electrons and electron neutrinos remains the same. The same applies to the muon and to the tau.

Incidentally, the neutrinos interact with matter so weakly that it takes gallons and gallons of their detector (chlorine-37) to detect them. But don't think neutrinos have no importance at all. When a star goes bust in an explosion called a supernova, it is the neutrinos that play the major role. And it is not just theory; neutrinos have been detected from supernovae.

Among the bosons there is the familiar photon, which is massless in the sense that its rest mass is zero. Then there are the *mesons*, which have masses (*meson* means "intermediate particle"; most mesons have a mass intermediate between the leptons and the baryons). There is one very interesting thing about these bosons. Whereas the fermions are the sources of force fields, the bosons seem to be the mediators of the interaction between two fermions.

The baryons and the mesons together belong to a family of particles, the previously mentioned *hadrons*, which interact via the strong nuclear interaction.

The Quarks: The End of the Quest?

Physicist Murray Gell-Mann, one of the most successful builders of models in elementary particle theory, has a weakness for literary expressions. Whenever he gets a chance, he injects some literary flavor in the otherwise abstract mathematical land of theoretical particle physics. He first came to prominence by showing that, in order to understand the previously mentioned hyperons, we must assign them a new quantum number that protons and neutrons do not have. He called this quantum number *strangeness*, which is a rather nice name for a quantum number. (This idea was independently proposed by Japanese physicist K. Nishijima.)

It was also Gell-Mann who discovered that a class of baryons, which includes the neutron, the proton, and some hyperons, can be described by a set of eight quantum states, together making up a family. He called his finding *the eightfold way*. (This idea was independently proposed also by Israeli physicist Y. Ne'eman.)

Whereas Buddha's eightfold way was designed to relieve the suffering of all humanity but never quite achieved its goal, Gell-Mann's eightfold way did temporarily relieve the suffering of many particle physicists who were groping in the dark trying to find ways to understand the mysteries of the baryons.

Then in 1964 Gell-Mann made his most daring proposal ever. He suggested that the neutrons and protons (and in fact, all hadrons—particles that interact via the strong nuclear interaction) are made up of even more elementary constituents, perhaps the ultimate elementary particles. To name them he got help from the literary master, James Joyce. Joyce, in his novel *Finnegan's Wake*, has a phrase, "three quarks for muster mark." Since Gell-Mann needed three of these elementary particles to make up a neutron or a proton, and since he is devoted to James Joyce, he called these particles *quarks*. (The idea of quarks was independently arrived at by G. Zweig.)

Incidentally, if you look it up in a dictionary, you will see that the word *quark* has many meanings, one of which is "rubbish." It is not known if Gell-Mann knew of this when he named his new elementary particles quarks.

The quarks are truly amazing particles. For one thing, they have a charge of one third or two thirds that of the electronic charge. This goes against a trusted axiom of physics—that charges occur only in quanta of one electronic charge. For another, when everything is said and done about the quarks, it may very well be (at least most physicists believe so) that no quark will ever see daylight. Quarks are destined to be forever confined within the baryons (and other hadrons, the mesons) they compose.

Let's go into a little more detail of how the quarks are supposed to make up the various baryons and mesons. The proton and the neutron are each made from three of two kinds of quark: the *up* or *u* quark and the *down* or *d* quark. (Don't pay much attention to the designations; they are arbitrary names given to distinguish the two quarks.) The *u* quark has a charge of $+{}^{2}/_{3}\,e$ (e is the electronic charge) and the *d* quark has a charge of $-{}^{1}/_{3}\,e$. Thus, the proton is imagined to be made up of two *u*'s and a *d*; then its total charge is $+{}^{2}/_{3}\,e + {}^{2}/_{3}\,e - {}^{1}/_{3}\,e = e$, which is correct. Similarly, if you picture the neutron to be made up of two *d*'s and one *u*, you get the correct charge of the neutron, namely, zero.

One thing was immediately clear to Gell-Mann. Because of the eightfold way, he knew that any such scheme of elementary particles must also explain the other particles that fall in the same class. So he introduced a *strange* quark, denoted by *s*, in order to explain the strange baryons, baryons that possess a strangeness quantum number.

For a time it was thought that these three types of quarks, *u*, *d*, and *s*, were all you needed to understand all the strongly interacting particles. For example, the mesons are seen to be made up of quark-antiquark pairs. (Particles have antiparticles that can annihilate them upon contact; antiparticles of quarks are called antiquarks—and don't worry about why the quark and antiquark are not annihilating each other. We are assuming that they orbit one another instead of coming together.) Then in 1974 a new class of particles was discovered in the newest particle accelerators. The first one of these made headlines worldwide and was called the J on the East Coast and Ψ on the West Coast of the United States (the particle was discovered independently by a group on the West Coast and another on the East Coast). It was soon established that these particles are like the mesons and can be understood as consisting of a quark-antiquark pair, except that their constitution demanded a new kind of quark. This quark was given a new quantum number, *charm*,

and the new quark was called a *charmed quark*. Soon still another quark, called the *bottom* (some name it *beauty*), was found followed by the *top* (or *truth*) quark. So now there are six quarks. And there is strong belief that the list stops here. Six quarks—just as there are six leptons: the electron, muon, and tau, and their three neutrinos.

We expect that elementary particles are point particles, geometrical points of mass or energy. Are the quarks point particles? This question has been answered affirmatively through ingenious analysis of the collision of high-energy electron beams with a target containing protons. In general, the results of such collision experiments depend on both the energy and the angle at which the collision occurs. But if a particle is composed of pointlike constituents, then at the very high energies of the electron projectiles, the results of the collision can be shown to depend on just one quantity. This one quantity is a complicated combination of the two quantities mentioned above, the energy and the angle. Physicist Richard Feynman pointed this out when he showed that the experimental results tend to give a clear indication that the protons are made up of point particles (Feynman called these partons). Thus, the elementary constituents of the protons, the quarks or partons, whichever you call them, must be point particles. In this sense the quarks can be regarded as elementary, just as the electrons are.

Still, some physicists are dissatisfied with the quarks. One main reason is that nobody has yet "seen" a quark, not even in the sense that one has "seen" an electron. That is, we have no evidence as yet that quarks can exist in an isolated state. But the proponents of quarks actually like this. If quarks are forever confined within the particles they make up, then perhaps they are the end of the quest for elementary constituents of matter. If we cannot isolate quarks, the question, What is a quark made of? may seem pointless. Even so, there are proposals around for sub-quark particles. (Apparently, two psychic clairvoyants, Annie Bessant and C.J. Ledbeater, were able to predict at the beginning of the 20th century that there are sub-quark objects. This has caused a great amount of interest among some particle physicists.)

One final historical note. I mentioned at the outset that the idea of elementary, indivisible constituents of matter (the *atomos*) was due to Democritus. It turns out that other Greek philosophers also contributed to this idea. One of them, Epicurus (supposedly the founding father of Epicurean philosophy—eat, drink, and be merry), talked about *minimae parte* (minimal parts) of the indivisible atoms that were destined to stay forever confined within the atoms. Thus it has been conjectured that the idea of the confined quarks really originated in the Greek atomic theory.

A New Picture of the Forces

Consider the interaction of two charged particles—for example, two electrons. In the field description (see Volume I of this book, Chapter 14), we commonly think of them as continuously interacting with each other's fields. But in quantum theory, the field (the electromagnetic field, in this case) assumes a graininess. The grains of the electromagnetic field are the photons. The interaction of two electrons now is pictured to arise from the exchange of photons.

Is this picture too difficult to grasp? Perhaps it will be a little easier to understand if

we use a technique proposed by Richard Feynman to picture this way of viewing the interaction of two electrons. First, we draw lines in space-time (called world lines) for the two interacting electrons in their initial state, before the interaction takes place (Figure 12.2). Then one of them emits a photon (the dotted line denoted by γ) at O, and the other one absorbs the photon at O'. This kind of diagram is called a *Feynman diagram* and is really a pictorial representation of a complicated mathematical procedure. A complete interaction between two electrons is given as a sum of several such photon-exchange diagrams that indeed add up to the good old Coulomb's law of electrical interaction.

In quantum field theory all interactions are mediated by the exchange of particles. The photons, as we saw above, mediate the electromagnetic interaction of all charged particles. Other bosons, called the mesons, can be thought of as mediating the nuclear strong force (Figure 12.3). Thus, a neutron and a proton may interact by exchanging a π meson, or *pion*. The man who first proposed this in 1935, Japanese physicist Hideki Yukawa, did so without any knowledge of the mesons whatsoever. The discovery of the π meson is a triumph of theoretical physics at its very best. The baryons and the group of mesons that take part in strong interaction are now collectively referred to as hadrons (strongly interacting particles).

The bosons that mediate the interaction between quarks are called *gluons*, an appropriate name since they are supposed to keep the quarks glued together. It has been known for some time that each of the six quarks mentioned above comes in three individual quantum states, an affair that particle physicists, in the tradition of Gell-Mann, describe by saying that each of the *flavors* of quark comes with three *colors*. Likewise, some of the gluons are called color gluons.

Along this line of thought, it is believed that the weak interaction (common to baryons, mesons, and leptons) is also mediated by bosons (named the *weakon* or *W* bosons,

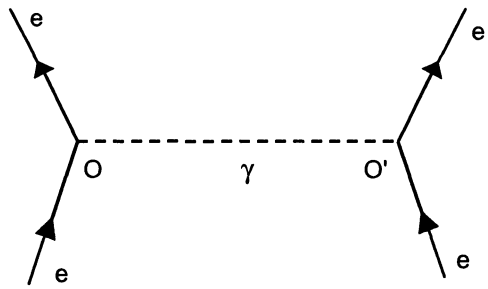

Figure 12.2
Feynman diagram for the interaction of two electrons with the exchange of a photon. One electron emits a photon (γ) at 0, which the other electron absorbs at O'.

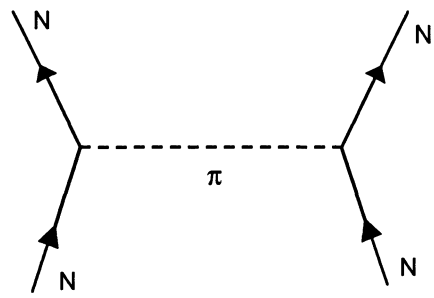

Figure 12.3
Feynman diagram for the interaction of two nucleons, denoted as N. Nucleons interact by exchanging a π meson, according to the theory of Hideki Yukawa.

also first suggested by Yukawa, and the so-called Z boson). Similarly, it is expected that the gravitational interaction also occurs via the exchange of a boson; this has not been discovered, however, but few physicists doubt its existence.

The latest work in this area is an attempt to give a unified description of the weak, the electromagnetic, and perhaps even the strong interactions in terms of a quantum field theory. The mediators of the interactions are the quanta of this unified quantum field; some of them are the old ones mentioned above, like the photon and the W boson, but now looked at as a class of similar particles. One cannot claim this theory to have provided "final" answers, but it is generally considered to be one with good possibilities. You probably know that Einstein spent the last years of his life looking for such a unification of the forces. So in a sense, Einstein's dream is coming true. The basis of the unification is the discovery of a new kind of symmetry, called the *gauge symmetry*.

Gauge Symmetry and the Unification of Forces

What is symmetry? You are familiar with the snowflake: if you rotate the snowflake by an angle of 60° about an axis through its center, you cannot tell any difference, the snowflake looks the same. This is an example of hexagonal symmetry. A sphere is symmetric under any rotation about an axis through its center—it has spherical symmetry. Our bodies are approximately bilateral-symmetric because they remain unchanged if left and right are exchanged about a vertical axis through the center (Figure 12.4).

So, in general terms, a body is said to be symmetric if it remains unchanged under a certain operation. Hexagonal and spherical symmetries are connected with the operation of rotation. Bilateral symmetry has to do with the operation of reflection. What kind of operation is the gauge symmetry connected with?

The word *gauge* refers to the measure or value of a physical quantity. Gauging means fixing the scale or the value of physical quantities. Gauge symmetries deal with re-gauging the scale or values of physical quantities; a system has gauge symmetry if its physical nature does not change under such re-gauging.

A simple example is provided by an astronaut in a spaceship, traveling in a straight line at constant speed deep into space, unencumbered by any force fields. Such a system has gauge symmetry, but how do we see that?

Well, make a gauge change, re-gauge or re-scale a quantity, in this case distance. Suppose the spaceship is traveling along a parallel pathway a mile away from the original track. Does such a gauge change of the distance affect anything physical for the astronaut? No, indeed. Under this kind of gauge change, which amounts to an identical translation of all points along the path, the laws of physics remain unchanged. Since the gauge change is the same at all points, we call it a global gauge transformation.

Be adventurous and imagine a gauge change that changes from place to place on the track—such a re-gauging is called a local gauge transformation. Now what? Does the physics still remain unchanged? Well, the astronaut is no longer moving in a stright line, and you know what that means. In order to follow a zigzag path, the spaceship has to fire its rockets this way and that way, and the astronaut would feel the pseudoforces of acceleration (see Chapter 16 of Volume I for an introduction to the idea of pseudoforce). No more symmetry?

But wait! Suppose there is a gravity generator nearby—a planet, for example—and every time the rocket fires, the planet is situated such that its gravity exactly cancels the pseudoforce of the accelerating reference frame. Now the astronaut does not feel any force and cannot tell any difference from being on the original straight-line path. So even local gauge symmetry is possible provided a gravitational force field is there to compensate. Elementary particle physicists turn this around and propose a new picture of gravity: gravity is nature's way of maintaining a local gauge symmetry—gravity itself is a local gauge field.

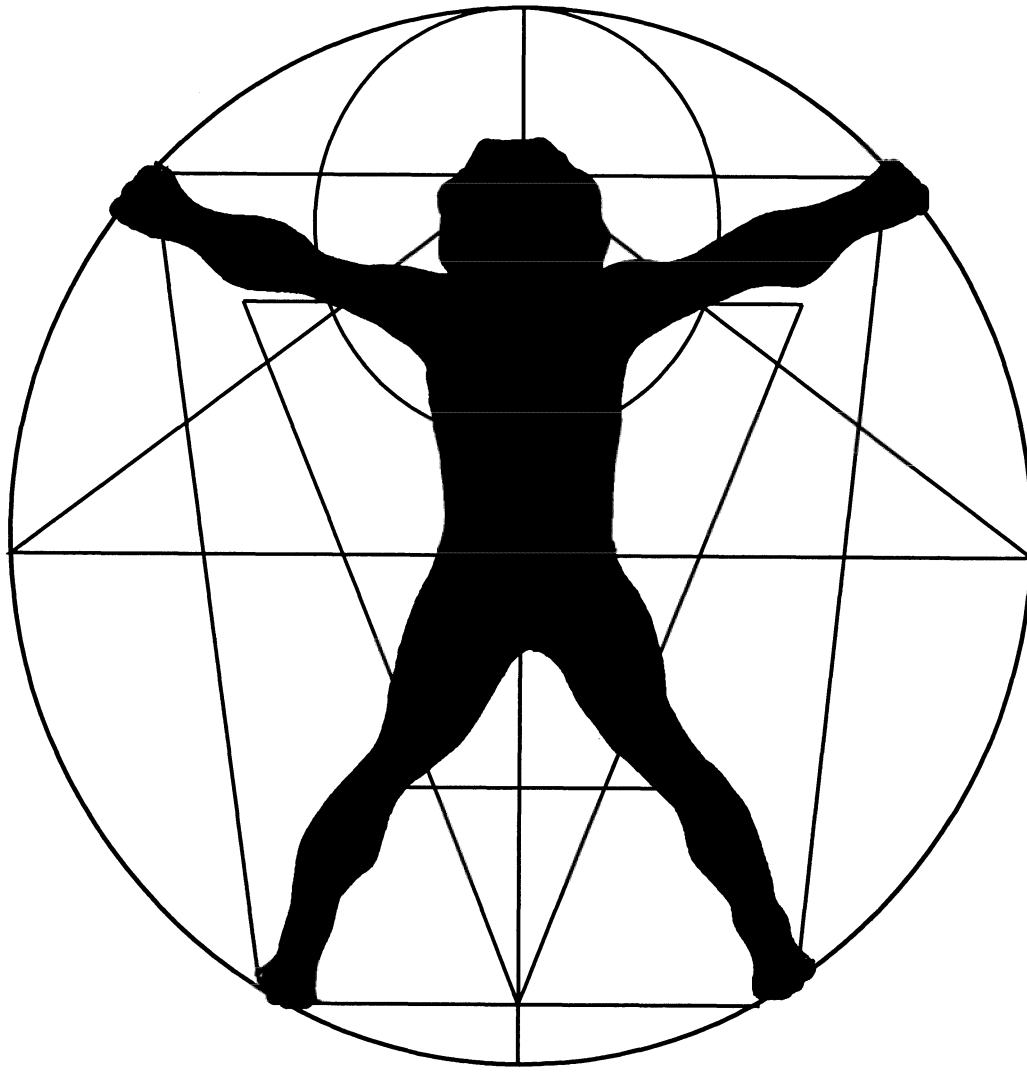

Figure 12.4
The human body is approximately bilateral-symmetric; the left and right sides are close to mirror images of each other.

So, similarly, all the known forces of nature can be regarded as some local gauge field. Indeed, Maxwell's theory of electromagnetism (see Chapter 14, Volume I) is the first known example of a physical theory that does not change under a local gauge transformation (which involves, in that case, a change in voltage from place to place, for example). So electromagnetic force fields are gauge fields, and lo! They are a unification of two different force fields, electricity and magnetism.

One of the great achievements of modern particle physics is that in the context of gauge symmetry it is easy to see mathematically the road to the unification of forces. So far, actual unification has been achieved only between the electromagnetic and the weak fields; this was the great accomplishment of American physicists Steven Weinberg and Sheldon Glashow and the Pakistani Abdus Salam, all of whom received the Nobel prize for their accomplishment. Hope runs high that soon all the forces will be unified. So physicists talk about a Grand Unified Theory (abbreviated as GUT), super-gravity, a Theory of Everything (abbreviated as TOE), and so forth, with great excitement in the hallways of various research centers. Some of the mathematical difficulties are solved if we introduce the concept of elementary particles as "strings"—infinitely long linear entities, rather than geometrical points. These string theories, in their turn, give bizarre pictures of the universe containing many dimensions of space-time that are "compacted" to make it look like the four (three space plus one time) dimensional one in which we live.

It is an exciting time for theories in the arena of particle physics, and something needs to be done in the experimental arena to keep the theorists honest. The superconducting supercollider was destined to tell us if the theorists are on the right track or if they are just weaving dream worlds. But alas! the cost of building such a machine is prohibitive and had to be abandoned. Still there is one great laboratory for these theories—the cosmos itself in its early moments. And there is much commendable activity for using this laboratory.

Some physicists believe that in the early moments of the cosmos, at the very, very high temperatures that must have prevailed, matter existed in a state of total gauge symmetry, and there was only one unified force among material objects. But as the universe cooled with subsequent expansion, the symmetries were broken one by one. This is similar to how water freezes with the lowering of temperature. Water is highly symmetric, it has no center and all directions are equivalent. But when water freezes into ice crystal, some directions become special, and we can discern a center; the symmetry of water is gone. So it can be with the primordial matter of the universe. Matter today exhibits differences in interactions because of broken symmetry.

The most important and also the most popular impact that elementary particle physics is making today is in the field of cosmology, especially in the theory of the very early history of the universe. There are many other unsolved cosmological questions that only elementary particle physics can tackle—Will the universe expand forever? What are the constituents of dark matter, which experimental cosmologists predict on the basis of their astronomical data? and so forth. The idea of dark matter needs elaboration. Dark matter is called "dark" because we cannot directly see such matter, yet indirect evidence for it is piling up. The observed density of the universe is not enough for the expanding universe to roll back and contract (see Chapter 17 of Volume I). The extra mass needed to make the universe stop its expansion and contract toward the big crunch in some distant future

is called "missing mass," which must be due to some missing matter. Dark matter is theorized also to fill the role of the so-called missing matter.

The research of the physics in this chapter is expensive. Mostly it needs expensive devices called *accelerators*, machines that speed up submicroscopic particles to enormous energy, which then are used to shoot at matter. But one should not be too put off by the expenses. When one of the latest, most sophisticated of the accelerators now built (at Batavia, Illinois) was proposed, its value was immediately questioned. The following is an excerpt from congressional testimony given by physicist Robert R. Wilson, who later became director of the accelerator center at Batavia.

Senator Pastore: Is the accelerator connected in any way with the security of our country?

Wilson: No, sir, I do not believe so.

Senator Pastore: It has no value in this respect?

Wilson: It only has to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with those things. It has nothing to do with the military, I am sorry.

Senator Pastore: Don't be sorry for it.

Wilson: I am not, but I cannot in honesty say it has such applications; but it has to do with whether we are good painters, good sculptors, great poets, I mean all the things that we really venerate and are patriotic about in our country. In that sense this new knowledge has everything to do with honor and country but it has nothing to do with defending our country except to make it worth defending.

CHAPTER 13

More Quantum Technology: Solid State Physics

Solid-state physics is the largest discipline of physics practiced today. *Solid-state physics* deals with solids and materials, and in general, with their thermal, optical, electrical, and magnetic properties. Of all these subfields we will discuss only one, the electrical properties. In particular, we will ask the question: What is the difference between conductors and insulators?

It has been well known for some time that there are also substances that are intermediate between a conductor and an insulator in their electrical attributes. Such substances are called *semiconductors*. In the 20th century, solid-state physics has initiated a revolution in technology, the most well known symbol of which is the transistor. As we will see, the transistor is based on the physics of semiconductors. And so are solar cells, which are devices that convert solar energy directly into electricity.

The Carriers of Electricity

How does an electric current flow through a conductor in an electrical circuit? The basic idea of our current picture is that in a conductor there exists an ample supply of current carriers—the so-called free electrons—that are relatively free to wander around inside the body of the solid. These free electrons constitute the basic difference between

A. Goswami, *The Physicists' View of Nature*
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conductors and insulators. In the atomic picture we can say that in a conductor some of the valence electrons (electrons that lie outside closed shells) are available in the entire solid as current carriers. The quantum wave of these electrons spreads itself through the entire lattice of the crystal. This is what we mean when we say that the valence electrons in a metal are bound to the entire metal, not just to the atoms. In contrast, the valence electrons of a nonconductor are cemented to nearby atoms; they are not available as current carriers. In an insulator this cement, or chemical bond, is so strong that an electron cannot be freed, short of melting down or evaporating the crystal altogether.

The semiconductors, as we said earlier, are intermediate between these two. The valence electrons are bonded to atoms, but not very strongly. Energy in the form of heat and light can free a few electrons from the atomic bonds and make a small supply of free-electron current carriers. Actually, it works even better than this picture implies. It turns out the electrons leave "holes" at their original sites upon thermal excitation to higher energy levels. These holes, or vacancies, of negative charge act as positive charge carriers. So when an electric field is applied to such a crystal with electrons and "holes," the electrons go one way and the holes the other way. But positive charge giving a current in one direction is the same as negative charge giving a current in the opposite direction. So the two currents add together to increase the net current.

This kind of picture can also explain why the performance of a semiconductor improves drastically with the addition of a small amount of specific impurities. Adding a small amount of impurity to a semiconductor is called "doping." Doping adds a ready supply of free electrons. As an example, consider the doping of silicon (Si) with phosphorus (P). Silicon has four electrons over and above the closed-shell atom neon, so it has four valence electrons. Phosphorus, if you look at the periodic table, has five electrons outside the closed-shell configuration of neon. So the number of valence electrons of phosphorus is five. Now if a phosphorus atom replaces an atom of silicon at one of the lattice sites (Figure 13.1), four of its valence electrons will bond with four neighboring silicon atoms, but the fifth one has nothing with which to make a bond and will be quite free. An atom that donates free electrons to a semiconductor with such doping is called an *n-type semiconductor*.

We can also think of donors of holes, or, behaviorally the same thing, positive charges. Consider silicon again, but this time doped with boron (B), which has three valence electrons (in the same way phosphorus has five). In this case three silicon atoms can fulfill their bonds, but the fourth bond is incomplete; it has a hole in it (Figure 13.2). Thus a boron atom impurity donates holes or positive charges to silicon, and in this case the semiconductor is called a *p-type semiconductor*.

Energy Bands in Solids

An even better understanding of the differences of electrical properties of conductors, insulators, and semiconductors is provided by the *energy band theory*, a detailed theory of the electronic energy levels in a solid. You know that isolated free atoms have energy levels often separated by large gaps (Figure 10.2). How does this picture change due to the presence of other atoms in a closely packed material such as a solid? What results from

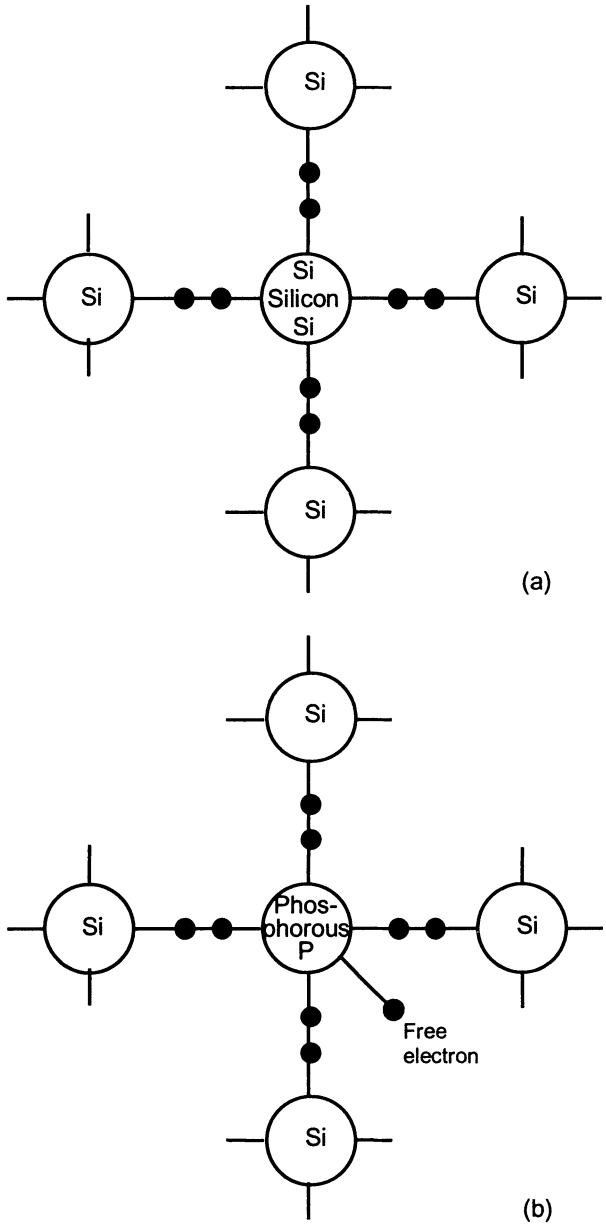

Figure 13.1
(a) The chemical bonding of silicon atoms in a crystal. (b) When a phosphorus atom replaces the silicon atom, it has one electron free (no available electron to bond with). This is called an *n*-type semiconductor.

the interactions is a transformation of each atomic energy level into a band of closely spaced levels (Figure 13.3). These are the *energy bands*. The number of levels in a band is as large as the number of atoms present in the crystal. Also, since the bands arise from the energy levels of free atoms, if a certain atomic energy level is filled, so will be the corresponding band. The electrons obey the Pauli principle and fill successively the levels of lowest available energy, as in the case of the isolated atom.

For a metal, the upper band, called the *conduction band* (Figure 13.3), is partially filled. Since the difference in energy between successive levels within a band is very small,

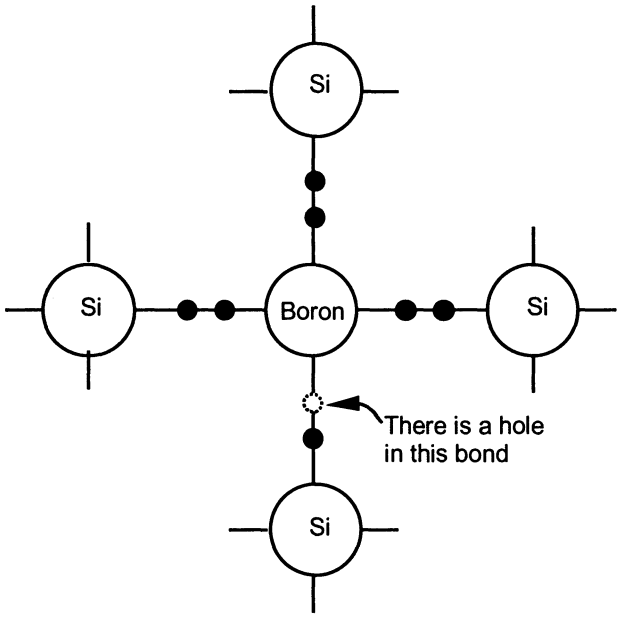

Figure 13.2
A *p*-type semiconductor. If silicon is doped with boron, replacing a silicon with boron atom, it leaves a hole in one of the bonds.

when a voltage is applied to a metal, the conduction electrons can accept some energy and get excited to a higher level within the band. They will now drift in the direction of the electric field. In an insulator, on the other hand, there is no electron in the conduction band, and the bands below it are filled. Since the energy difference between the highest completely filled band (called the *valence band*) and the conduction band is large, if we supply a small amount of energy by means of a regular-sized voltage, the energy is not going to be enough for individual electrons to overcome the energy gap and reach the empty band. Since the energy of the electron in a solid is allowed to have only the values permitted by those of the levels lying within the bands, it follows that the electrons in an *n*-type insulator cannot accept energy and flow with an applied voltage. Thus, the insulator property really originates from quantum effects, from the graininess of energy.

The conduction band is empty in semiconductors also, but now the energy gap between the filled valence band and the unfilled conduction band is not so large as in insu-

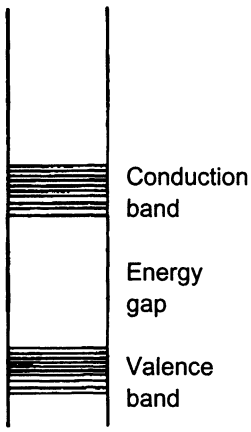

Figure 13.3
Energy bands in solids. Usually there is a large energy gap between the conduction band and the valence band. Insulators have the valence band completely filld, but the conduction band is empty. Thus, electrons in an insulator cannot accept a small amount of energy and then flow when a voltage is applied; there is no energy level the electron can go into with just a little bit of energy. Conductors, on the other hand, have their conduction bands partially filled, and therefore the electrons have many energy levels to go into when they are given a small amount of energy by an applied voltage.

lators (Figure 13.4). Even thermal excitation is now enough to enable a few electrons in these substances to go over the energy gap and reach the empty band. These electrons can now be accelerated by an applied electric field to give a current.

It is also clear that as thermal excitation lifts an electron from the valence band to the conduction band, there is a hole left in the latter. The hole can propagate and conduct electricity in the following way. The valence band is now unfilled, and an electron in this band can gain energy from an applied electric field and fill the vacancy. But this electron itself leaves a vacancy, which some other electron, upon acceleration and gaining energy from the applied field, can occupy—creating in its turn a vacancy. Thus we find now that the vacancy is propagating.

The introduction of "impurity" atoms introduces either further conduction electrons or further holes in the valence band. In either case there is an increase of the current carriers of the semiconductor, and it becomes a better conductor.

The Solid-State Rectifier

Now we are ready to consider a *p-n* junction, a junction of an *n*-type semiconductor with a *p*-type one. The *n*-type semiconductor has free electrons, and the *p*-type has free holes (Figure 13.5). Some of the free electrons from the *n*-region will flow into the *p*-region by ordinary diffusion, the same process by which a vial of open perfume mixes with the adjacent air. (Free electrons in solids behave in some ways the same as free mol-

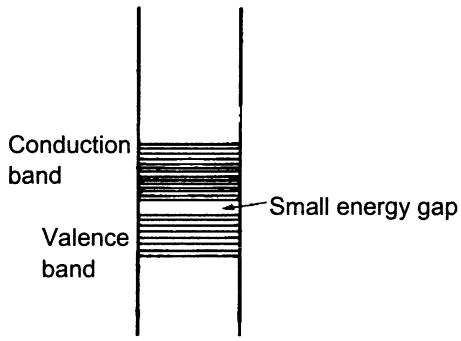

Figure 13.4
Semiconductors are characterized by a small energy gap between the last filled and the first unfilled bands.

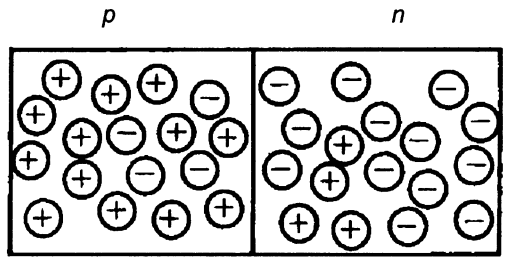

Figure 13.5
A *p-n* junction. In the absence of an applied voltage, some electrons (-) find their way into the *p*-region and some holes (+) find their way into the *n*-region.

ecules in a gas. This is the reason that a collection of free electrons in a solid is called an electron gas.)

This is accompanied by the diffusion of holes from the *p*-region into the *n*-region. The result of both motions is to make the *n*-side somewhat positively charged and the *p*-side simultaneously negatively charged by the same amount. The opposite charges on the two sides will provide an attractive force, which will make further migration difficult. Thus, an equilibrium situation will be established in which there will be a few electrons among the holes on the *p*-side and vice versa for the *n*-side.

Perhaps you are thinking that electrons and electron holes existing side by side on both sides should neutralize each other (the electron can jump into the hole). Such neutralization does occur (but at a slow rate), and so some diffusion must continue to make up for the neutralization.

Now imagine that we apply an electric voltage to the two sides of the *p-n* junction (Figure 13.6). If we connect the negative terminal of the battery to the *n*-type crystal and the positive terminal to the *p*-type crystal, there will be a force driving the electrons to the left and holes to the right (remember, electrons flow from the negative to the positive electrode; since holes are equivalent to positive charge, they flow from the positive to negative terminal). The net direction of both currents is the same; they augment each other. As there is a larger number of electrons moving in the *p*-region, more of the holes will be neutralized, and the same is true for the *n*-region due to the invasion of the holes. Thus, both sides need a fresh supply of electrons or holes, as the case may be, which is precisely what the job of the battery is. So the current will continue.

If, on the other hand, we connect the positive terminal to the *n*-side and the negative terminal to the *p*-side, the situation is messed up. The electrons are still pulled to the positive terminal and the holes to the negative terminal, but this just pulls them both away from the junction, creating an empty region in between (Figure 13.7). There cannot be any current in this case; the current stops. This device then allows current in one direction only and is therefore able to "rectify," or make a DC current out of an AC current.

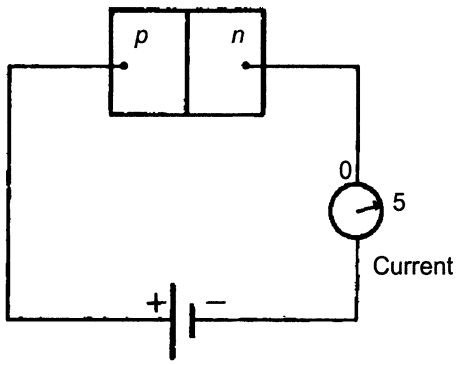

Figure 13.6
The *p-n* junction connected to a battery the "right" way. The current continues.

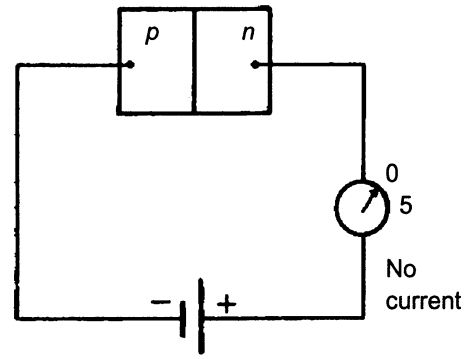

Figure 13.7
The *p-n* junction connected to a battery the "wrong" way. The current stops.

The Solar Cell

We have seen how an applied electric voltage can affect the equilibrium situation existing in a *p-n* junction. The equilibrium can also be affected by radiation; if sunlight falls on one side, it will release electrons from that crystal by knocking them out. Just as a voltage offsets the equilibrium of the junction, offsetting the equilibrium junction with sunlight will generate a voltage. This is the principle of the solar cell.

The big advantage of the solar cell is that we don't have to go through the intermediary of thermal energy in converting solar energy to electrical energy. Thus, there is no limit imposed by the second law of thermodynamics on the efficiency of conversion. At the present time, solar cells have been built with an efficiency of only about 15%, but the situation is expected to improve in the future.

The major disadvantage of using a solar cell on your rooftop to satisfy your electrical need is an economic one. The material needed for solar cells, pure silicon, is very costly. Currently electricity generated by a solar cell is 50 to 100 times costlier than that obtained from conventional methods.

The Transistor

One of the most significant changes to occur in modern technology has been the replacement of the vacuum tube with transistors, which are made out of semiconductor *p-n* junctions sandwiched back-to-back (Figure 13.8). We can easily understand how the transistor works from what we have discussed before about the *p-n* junction.

The transistor has three distinct regions, which are variously connected to the input signal to be amplified, to the power source (batteries), and to the output circuit accepting the input signal. The battery on the left in Figure 13.8, connected to the *n-p* junction, is a low-voltage battery and it is connected to the *n-p* junction in the correct way to give a

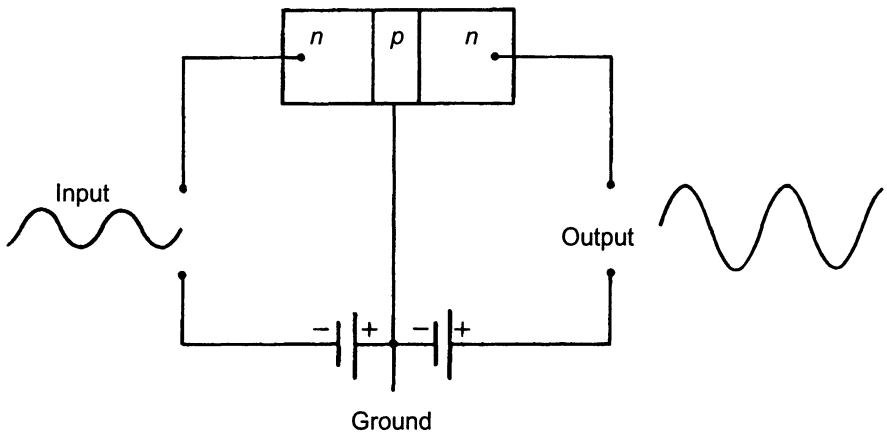

Figure 13.8
A transistor, or *n-p-n* junction, as an amplifier.

relatively large current, as explained before. The incoming signal voltage is, of course, superimposed on the constant voltage of the battery, and this produces a large variation of current across the junction. The net result is that the *p*-region is getting a large influx of electrons from the left, which varies with the voltage of the incoming signal.

Now look at the *p-n* junction on the right. This one is connected to a high-voltage battery, but in the wrong way; the negative pole of the battery is connected to the *p*-region and the positive pole to the *n*-region. As we saw earlier, when the *p-n* junction is connected to a voltage source this way, it hardly transmits any current at all. However, there is a difference in this case; there is a large influx of electrons coming in from the left. This will diffuse to the right, giving a current that can be as large as the current in the input circuit if the design is correct.

This does not sound so spectacular. Actually, though, something great has been accomplished. The voltage fluctuation in the input signal is small, and it produces a certain current fluctuation. But now the same current fluctuation, as it passes through the junction on the right, is accompanied by a large voltage fluctuation. In other words, the signal in the output circuit is an amplified one. Thus the transistor serves the same role—that of an amplifier—as does an old-fashioned valve or triode. Its advantages over the triode are tremendous savings in space and greater reliability and performance.

In today's microelectronic circuits, a one-inch square of silicon may hold some 100,000—even millions of transistors of this kind. As a result, it has been possible to manufacture devices like the pocket calculator and the laptop computer.

The Importance of Quantum Technology

Admittedly, the subject of this chapter, some of it anyway, is quite technical. In a book in which the emphasis is on metaphysical questions, why delve into details of technology? The reason is that I don't want you to think that quantum physics is all theory with few practical applications. Too many people disregard the "weird" metaphysical aspects of quantum physics because they think quantum physics is "just theory." No, quantum physics is no ordinary theory; its predictions have all been verified without exception, sometimes with an accuracy of one part in 100,000,000. And on top of that, quantum technology is so ubiquitous that we practically use it every day. So it is that quantum physics must be taken seriously—weirdness and all.

Quantum World at a Glance

The development of quantum mechanics mostly occurred in conjunction with the physics of the atom, in particular atomic spectra, and the physics of the continuous spectrum of light emitted by incandescent solids considered by Planck. With gases we can get two other kinds of spectra: the emission line spectrum and the absorption line spectrum. The emission spectrum occurs when an electron of an atom makes a transition to a lower state from an excited energy state. The opposite case—where an electron absorbs incident light energy to make a transition from a lower energy level to a higher one—gives us the absorption lines. A landmark in the history of science was established when Niels Bohr,

with his atomic theory, explained the Balmer series of emission lines of the hydrogen atom. One of the spectacular applications of the atomic theory of light is the laser, which uses "stimulated emission."

The quantum theory of the atom also explains some puzzling things that the chemists discovered while classifying the chemical elements in the so-called periodic table. The physicists' explanation of the periodic table rested on the following ideas. The first is that of quantum numbers; each of the stationary states of the atomic electron is characterized by a set of four discrete numbers called the quantum numbers. The second idea is the Pauli exclusion principle: no two electrons can have an identical set of the four quantum numbers. And the third idea is simply that, in order to form the ground state, the electrons occupy in order the states of lowest available energy.

The Pauli principle also plays a role in the stability of white dwarf stars—one of the end points of stellar evolution—where it provides an outgoing (Fermi) pressure to balance the inward pressure of gravity.

In the heart of the atom are the atomic nuclei notorious for their destructive powers unleashed through the invention of the atomic bomb. Even nuclear power, heralded as the peaceful use of nuclear energy, is not particularly popular because of its potential pollution hazard and safety problems. Nevertheless, nuclear physics does have truly peaceful applications such as radioactive dating. Today, nuclear physics is providing an important laboratory for studying the interaction of the ultimate constituents of matter, the elementary particles.

Elementary particle physics is introduced with a new picture of force as its center point. There is now considerable excitement that all the forces of nature may have originated from one unified force via symmetry breaking.

The gift of the quantum world to modern technology is the wonder of solid-state physics through new inventions such as transistors.

Part FOUR

THE PARADOX OF THE QUANTUM

CHAPTER 14

Quantum Nonlocality

A very important event in the history of the paradigm shift that quantum physics is bringing about was the extended debate that took place between Niels Bohr and Albert Einstein in the 1920s and '30s. In these debates, Einstein was always trying to posit to Bohr some conceptual difficulty or some paradox with quantum thinking, and Bohr was always successful in finding a satisfactory answer to Einstein. This went on for a while between the two men, and then the debate became public. The debate reached its absolute height when Einstein, with the help of two young collaborators Boris Podolsky and Nathan Rosen, published a paradox in a physics journal, now famous as the Einstein-Podolsky-Rosen paradox, or the EPR paradox. In contrast to earlier ones, in this paradox Einstein succeeded in pointing out one of the most fundamental aspects of the quantum view of the world, an aspect that is now called *quantum nonlocality*. The EPR paradox eventually led to laboratory experiments that verified quantum nonlocality. And all the wonderful things about the new paradigm, the new interpretation of quantum physics included, which you are reading in this book, were inspired by these experiments.

What is locality? Locality is the idea that all interactions between objects are mediated by force fields or signals that travel through space a little bit at a time, always taking a finite time. Through his theory of relativity, Einstein was able to show that there is a maximum speed limit for nature's highways of space—the speed of light—and all signals and force fields are restricted to travel within the bounds of this speed limit, which is 300,000 km/s. So what is nonlocality? *Nonlocality* is an instantaneous influence that travels from one

A. Goswami, *The Physicists' View of Nature*
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object to another (or from one part of a body to another part) without the interchange of any local force field or local signals. One experimental signature of nonlocality is that it is faster-than-light communication.

Now about the EPR paradox and how it proves quantum nonlocality. Recall the uncertainty principle–at any given instant, both the position and the momentum of an object cannot be measured with absolute certainty–errors or uncertainties creep in. For computing the trajectory of an object, we can start with its initial position, but then we also need to know where it is going and with what speed. But if we know position accurately, we cannot know the velocity with equal certainty; hence the impossibility of predicting the trajectory of a quantum object. EPR constructed a scenario that seemed to contradict this compulsory unpredictability.

Suppose two electrons, call them Joe and Moe, interact for a time and then stop interacting. While they are interacting we can assign them positions x_J and x_M and momenta p_J and p_M along some axis. Quantum mechanics does not allow us the simultaneous knowledge of x_J and p_J or of x_M and p_M, but, interestingly, allows us the simultaneous knowledge of $x_J - x_M$ (the relative distance of Joe from Moe) and $p_J + p_M$ (the total momentum of Joe and Moe). All this is summarized in Figure 14. 1.

Now look here, says EPR, Joe and Moe are correlated, a correlation that lasts even when they are not interacting. How so? If we collapse Joe's position by measuring that variable, Moe's position is determinable since we know their relative distance from each other. If we collapse Joe's momentum by measuring it, Moe's momentum becomes determinable from our additional knowledge of their total momentum. So there is something strange here–a paradox! *Either* (if we assume locality, that is) agree that measurement of Joe cannot affect Moe since there is no local interaction between them, then the values of both position and momentum of Moe become simultaneously accessible, and therefore the trajectory of Moe is calculable, although quantum mechanics, because of its

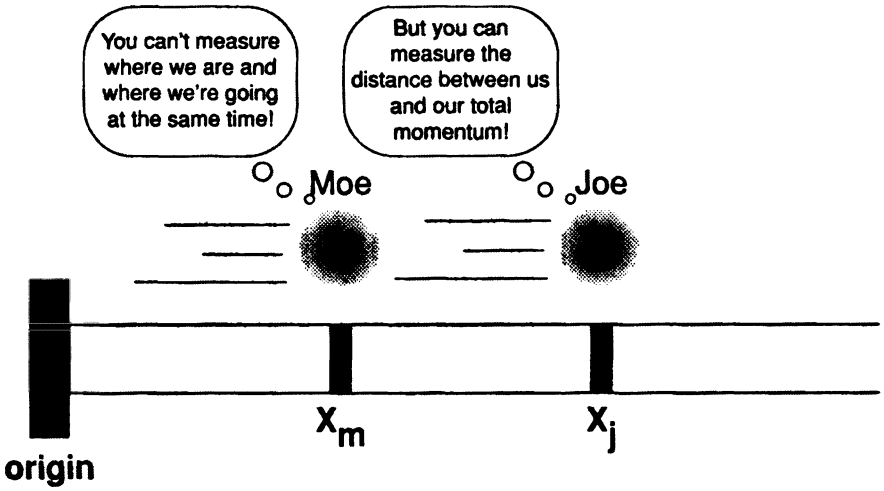

Figure 14.1
The EPR correlation of Joe and Moe. The distance between them, $x_J - x_M$, is always the same, and their total momentum is always $p_J + p_M$. (Reprinted with permission from Goswami, A., *The Self-Aware Universe*, NY: Tarcher/Putnam, 1995.)

adherence to the uncertainty principle, cannot calculate it. Conclusion: quantum mechanical description of two correlated objects is incomplete. We must replace quantum mechanics with some kind of hidden variables theory. The idea is that the knowledge of these hidden variables will allow us the theoretical calculation of trajectories of quantum objects. *Or* the locality principle is violated, implying the violation of the sacrosanct theory of relativity.

Einstein sympathized with the first option, hidden variables. He never liked quantum mechanics because of its statistical implication–the outcome of things cannot depend on a random role of the dice by a dice-playing God, he maintained. Bohr pointed out the correct implication of the correlation–quantum nonlocality. Bohr argued that there is an inseparability between the measurement of Joe's position and Moe because of their correlation–Moe is affected by the measurement of Joe, Moe's possibility wave also collapses when Joe's does, although the collapse then clearly is nonlocal.

Ultimately, of course, this kind of ontological argument can only be settled experimentally. Do correlated quantum objects exert nonlocal influence on one another? Is quantum collapse nonlocal? Can these be made into experimental questions? They were, and this began what is now hailed as experimental metaphysics. The major players in this arena were two theoretical physicists, David Bohm and John Bell, and two experimental groups, one consisting of John Clauser and Stuart Freedman at the University of California in Berkeley, and a second one headed by Alain Aspect in France.

Before we go into Bohm and Bell's work, one more way to think about quantum nonlocality. Quantum nonlocality, the correlation above, is a phase correlation, the reason that it is also called phase entanglement or simply entanglement. What does this mean? Suppose you are dancing with a partner. When your hand goes up, so does your partner's–this is a phase correlation. Of course, you are dancing to music, and you are also seeing your partner, so it is easy to maintain this phase correlation with the help of those local signals. Now imagine that there is no music, and you are separated in locally isolated rooms. Can you still dance in a phase-entangled way? That would be amazing, wouldn't it? This is what EPR correlated electrons routinely do. And it is more than amazing, it is weird that we have actually taken the snapshots of such objects while they do their tango!

Singlet Bohm, Singlet Bell

It is hard to experiment with electrons correlated the way EPR envisioned. How can we get the two correlated electrons outside of each other's local interaction, once they have interacted, to measure if the correlation persists even when they don't "see" each other locally? David Bohm pointed out that electrons have a two-valuedness called *spin* that can be used to this purpose. What is spin? I know, when you hear the word spin you immediately think of objects rotating about their own axis, but quantum spin is not anything like that. Instead, think of it as some two-valued quantity: an electron can either assume one value or the other. It's as if an electron has an arrowhead that either points up or down (see also Chapter 10).

Bohm pointed out that under certain conditions, two electron collide in such a way that after the collision their spins become correlated: if one's spin arrow points down, the

other's spin-arrow points up, and vice versa. The spin arrows are allowed both possible values individually, but their phases are entangled. Such electrons are said to be in a *singlet state.*

Not only the electron has two-valuedness—photons, the quanta of light, do also. Their two-valuedness is called *polarization.* You should be familiar with the concept of polarization from your use of polaroid sunglasses, which help avoid the glare of reflected light. Polaroid sunglasses have an axis, the vertical direction of the glasses as you wear them normally while standing. Ordinary light can be thought of as having both polarizations—along (A) and perpendicular (P) to this axis. When an ordinary, unpolarized beam of photons passes through the polaroid sunglasses, the light becomes polarized because the glasses allow only photons with polarization aligned along their axis (that is, those with the correct alignment—only half of the photons) to get through. To test this, verify that if you hold two pairs of polaroid sunglasses—one horizontally and the other vertically—in the path of a beam of light, no light will get through.

Now to John Bell's crucial work. Do quantum objects really behave nonlocally as predicted by quantum mechanics, or are there local hidden variables that call the shots from behind the scene? Quantum mechanics says that unpolarized photons are superpositions of two polarizations: polarization along and polarization perpendicular. When two photons are correlated in a "singlet" state of polarization correlation, which is the case of photons emitted by the decay of suitably laser-irradiated calcium atoms, then whenever we collapse one of them in the state A, the other is also collapsed in the state A. This should be easy to verify. If we set up two detectors with polarization axes parallel, then both should detect a photon. If, on the other hand, we set them up with polarization axes perpendicular to one another, then if one detects a photon, the other one should not. But there is a catch here! How do we know that the photons do not already have assigned polarizations to agree with these results? Suppose there is a yet-to-be-discovered deterministic hidden variable theory, and photons are not described by possibility waves, and can be assigned a definite value of polarization always. Then the above data just means that the photons had their polarizations aligned in the first place when they were emitted from the calcium atom.

Here is where Bell's ingenuity came to be useful. Bell showed that although, for simple detector alignments, the quantum mechanical result can always be explained also by assuming hidden variables, this is not so when the two polaroid detectors are aligned at an angle. In the latter case, if we assume local hidden variables, inequalities hold—these are the famous *Bell inequalities*—contrary to quantum mechanics.

I want to give you a flavor of Bell inequalities following the simple and elegant derivation by physicist Nick Herbert. Define a quantity, polarization correlation, PC, whose value depends on the angle between the two detector axes. Obviously, PC = 1 if the angle between the detector axes is 0° when the detection sequences at the two detectors are exactly the same:

Joe detector: A A P A P P A P

Moe detector: A A P A P P A P

Also obviously, PC = 0 if the two detector axes are at an angle of 90°. The detection sequences are now found to be:

Joe: A A P A P P A P

Moe: P P A P A A P A

Note that in each sequence given in these examples, the number of Ps and As are equal. This is because the photons are unpolarized and in a long sequence of detection, the number of photons polarized along the detector axes should be equal to the number of photons polarized in the perpendicular plane.

What is the value of PC for an angle intermediate between 0° and 90°? We can use quantum mathematics to calculate PC at any angle. For example, for 30°, the quantum mechanical value of PC is $^3/_4$. For every four photon pairs detected, the number of hits is 3, and the number of misses is one. We can also say that the error rate is $^1/_4$:

Joe: A A P A P P A P

Moe: P A P A P A A P

Do local hidden variable theories always give us the same answer for PC or the error rate as does quantum mechanics for any angle? Suppose we assume that for a 30° angle, a local hidden variables theory gives the same answer as quantum calculation. But now we can show that for twice the angle, 60°, the hidden variable answer cannot be the same as the quantum answer.

Here's why. We start with both detectors parallel and the observed sequences are identical (Figure 14.2a)). We now change Joe's setting by 30° (Figure 14.2b)); now the sequences will contain error—one miss out of every four, on average. Likewise, come back to the parallel setting, and this time rotate Moe's apparatus through 30° (Figure 14. 2c)), and again the error rate is one out of four. Obviously, the results are independent of the distance between the detectors. For all we know they could be continents apart.

If hidden variables are local, this much is certain. Whatever we do at Joe's location cannot change anything at Moe's location, and vice versa. So suppose from a parallel setting, Joe and Moe both turn their detector axes by 30°, so that the angle between the two detectors is now 60° (Figure 14.2d)). If locality is valid, each manipulation can only introduce an error rate of $^1/_4$ without affecting the other, and so the total error rate is now $^1/_4 + {}^1/_4 = {}^1/_2$. Except that sometimes Joe's error may cancel out Moe's; so the correct expression of the error rate is an inequality: the error rate is less than or equal to $^1/_2$. This must be the hidden variable answer for the error rate for 60°. On the other hand, quantum calculations give the value of $^3/_4$ for the error rate at the angle 60°. Hence Bell's theorem:

Hidden variables, in order to be compatible with quantum mechanics, must be nonlocal.

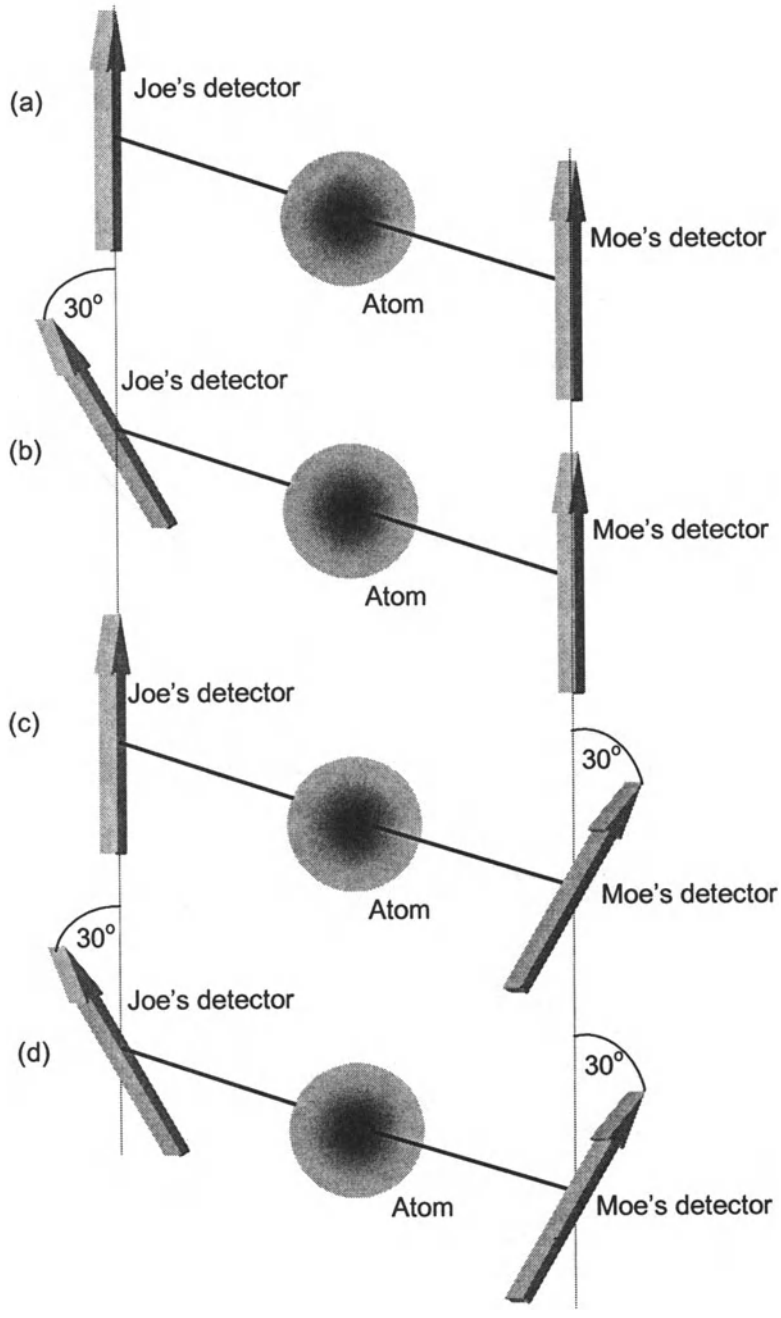

Figure 14.2
(a) We start with both detectors parallel, and the observed sequences are identical.
(b) The next step is to change Joe's setting by 30°.
(c) Next, return to parallel, and then move Moe's setting by 30°.
(d) Finally, from a parallel setting Joe and Moe both turn their settings by 30°.

Since the two predictions, local hidden variables and quantum mechanical, are different, we can discern between the two theories via laboratory experiments. And this has been done. As early as 1972, Berkeley physicists John Clauser and Stuart Freedman experimentally verified that Bell inequalities are indeed violated, and quantum mechanics vindicated. Then the French physicist Alain Aspect and his collaborators did their famous experiment in 1982. In this experiment, Aspect and his colleagues not only verified a Bell inequality, but also directly showed that there were no local signals between one detector station to another–there wasn't time. The experimenters, who were detecting a pair of photons simultaneously emitted in opposite directions from laser-irradiated calcium atoms with polarization detectors, switched (mechanically, of course) one of the detector axis-alignments faster than the travel time of light from one location to the other!

Aspect et al did their experiment when a laboratory distance separated the two detector locations. In the 1990s the experiment was successfully repeated with distance between the two detectors increased to over a mile. In this way, a most important aspect of the classical physics worldview, locality, is found to be violated and the implications are significant. At a physics conference in the 1980s, one physicist was overheard saying to another, "Anybody who is not bothered by Bell's theorem has to have rocks in his head." So what more do we find out when we *are* bothered?

The Meaning of Bell's Theorem and Aspect's Experiment

One consequence of Aspect's experiment and Bell's theorem is that if there are hidden variables as Einstein hoped, these hidden variables are nonlocal. They must represent an order of reality that is outside of space and time, a hidden reality that David Bohm calls the implicate order of things. The ordinary space-time order of reality Bohm calls the explicate order of reality. In Bohm's hidden variables theory and philosophy, the implicate order guides the explicate through an action-at-a-distance called the nonlocal *quantum potential.*

Bohm analogizes Aspect's experiment to the situation in which a fish in a tank is being seen in two distant TV sets as two distinct pictures. Whatever one fish does, the other fish reciprocates, but this is because they are the pictures of the same fish. If the fish images of the explicate order are assumed to be the primary reality, what is seen is strange. But in terms of the real fish of the implicate order, it is quite simple.

Bohm's nonlocal hidden variables theory is a good approximation to quantum mechanics, but it is not the exact equivalent. How do we understand quantum nonlocality in the standard picture of the collapse of the wave function? By realizing that the process of collapse is nonlocal. If collapse is nonlocal, then the agent of collapse is also nonlocal.

What is the agent of quantum collapse? This is the million-dollar question, and there is still no universally accepted answer. I will discuss the debate on this issue in the next chapter, but suffice it to say for now that presently there is only one philosophically astute answer: we, the observer consciousness, are the agents of collapse (see Chapter 18). But if we are the agents of collapse and collapse is nonlocal, then we must have a nonlocal being beyond our local and ordinary states of consciousness.

This opens up the notion that perhaps paranormal phenomena, such as telepathy or mind-to-mind communication without signals, takes place via quantum nonlocality. But

many quantum physicists object to this because telepathy involves a transmission of a message. In Aspect's experiment, there is a peculiar, even weird correlation between events that we see in one location and what we see in another location. However, the events that we see in one location only are completely random. After an event that shows a photon in the A state in one detector location, the next event in the same detector location is random. A photon may show up in either the A state or the P state. This randomness of events at any one place also means that there is no message in the sequence of events in any one place.

There is weirdness only when we bring the results collected at the two detector sites together. Then we see that events at one place are correlated with events at the other place, that there is a nonlocal communication, an influence that somehow went between the two locations without signals. The psychologist Carl Jung has called meaningful but acausal events of coincidence (or at best, events with a common cause) *synchronicities*. The quantum situation is more like Jung's events of synchronicities.

Is there, then, no possibility of understanding the paranormal in terms of quantum nonlocality? There is (see Chapter 22), but first we have to understand quantum measurement and collapse better, and then the role of consciousness in the collapse event more fully. So in the next chapter we will go in more detail into the discussion of quantum collapse. Is collapse even necessary?

Bibliography

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Putnam/Tarcher, 1993.

Herbert, N. *Quantum Reality*. NY: Doubleday, 1985.

CHAPTER 15

The Paradox of Schrödinger's Cat

Einstein's critical comprehension of quantum mechanics, expressed as the EPR paradox with the help of Podolsky and Rosen, led to the idea of quantum nonlocality, a crucial blow to the philosophy of material realism. Erwin Schrödinger himself had misgivings about the weirdness of quantum physics, his own discovery. He expressed his misgivings in the form of a paradox now called the *paradox of Schrödinger's cat*. And this paradox also has exposed insurmountable difficulties for the material realist metaphysics.

Here is the paradox. Suppose we put a cat in a box in the company of a single radioactive atom with a half-life of one hour. A few other things are also in the box—a Geiger counter, a hammer, and a bottle of poison—and they manage to couple the fate of the cat to that of the atom in a most peculiar way. If the atom decays, the Geiger counter ticks. The triggering of the Geiger counter activates the hammer, which then breaks the bottle of poison, releasing the poison that kills the cat. What can we say about the condition of the cat after an hour (Figure 15.1)? The atom has a fifty-fifty chance to decay, so at the end of an hour the single atom becomes a superposition of an atom that has decayed and an atom that has not decayed. The atom's dichotomy propagates to everything that comes after, including the cat. In short, the cat becomes a superposition of a dead cat and a live cat.

If this itself sounds paradoxical, that is one message that Schrödinger is trying to convey. If quantum thinking is allowed to invade the macroreality of our experience it leads to such strange consequences as a cat being both alive and dead simultaneously.

A. Goswami, *The Physicists' View of Nature*
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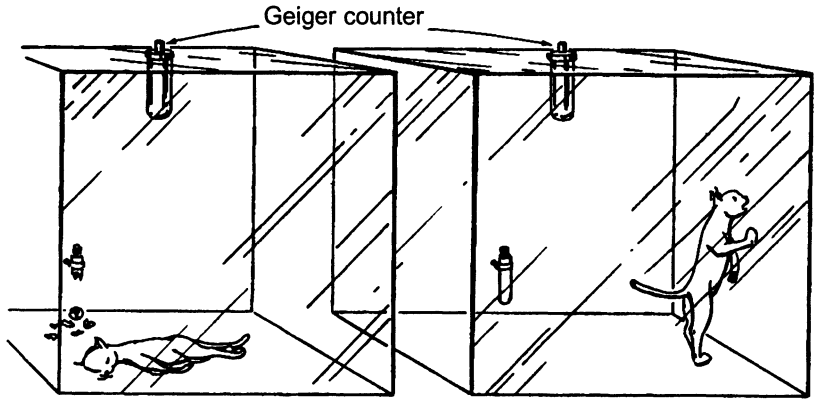

Figure 15.1
After an hour, will the cat be dead, as on the left, or will it still be alive, as on the right? Or will it end up half alive and half dead, which a literal application of the quantum mechanical probability rules would suggest as the answer? This is Schrödinger's cat paradox.

In standard quantum thinking, however, this is not all that strange! The cat is a superposition of a dead cat and a live cat, but this is in the domain of possibilities. Strange possibilities can coexist without causing conceptual quandaries. The problem here is, how does possibility become actuality? And when? What is the causal element behind the collapse of possibility into actuality? If it is our observation that collapses the cat's dead/alive dichotomy to a unique actuality of either dead or alive, then that raises the specter of subject-object mixing. And more. If consciousness is brain epiphenomenon, it cannot have any causal efficacy—so how can it be instrumental for collapse? Moreover, if the collapse is discontinuous, as standard quantum thinking posits, then there is the specter of the breakdown of rationality as well.

Many resolutions of Schrödinger's cat paradox have been proposed to save us from quantum weirdness, either to keep things strictly within material-realist premises, or at least exclude us subjects from playing any decisive role in the resolution of the cat's fate. But none of these resolutions has succeeded. I will take you through a number of these proposed resolutions. It is certainly interesting to examine them.

Let me also make some comments at the outset on a subject that is called decoherence. Quantum possibility waves, which are phase-coherent superpositions of possibilities, are expected to interact with their environment and lose their phase coherence. This is called decoherence. And this fact itself can be regarded as a "measurement." But this is faulty reasoning. What happens due to the interaction of a quantum system with the environment is that the system gets bigger (system + environment) and the phase relationships get more tangled, but complete decoherence never happens, cannot happen. This is because all objects, environment included, are quantum objects. Coupling possibility to possibility gives you bigger possibility and more complex phase relationships that may make the phase coherence very negligible, but it can never give you actuality! So the measurement problem, which is the problem of conversion of possibility into actual event, remains.

The Statistical Interpretation

The easiest way out of the cat paradox is the ensemble/statistical interpretation—the assertion that quantum mechanics only makes predictions about experiments involving large number of objects and/or events, and it is not meant to be used for single objects or single events. If there were 10 billion cats each in individual boxes set up as in Schrödinger's paradox, quantum mechanics would correctly predict that half of them would be dead at the hour and half would remain alive. And surely an experiment would verify the quantum mechanical prediction. But to worry about the fate of one cat? Forget it.

But how can we forget? We can certainly do experiments with single quantum objects even in the microscopic domain—that technology is already available. Quantum physics was designed for single objects, and by all indications (remember the discussion of the double-slit experiment) it holds for single objects.

And if it is all statistical, a random roll of the dice that figures in the fate of the cat, then Einstein's agony, "I cannot believe that God plays dice with the universe."

Bohm's Hidden Variables: Discontinuous Collapse Is Not Needed— a Continuous Causal Agent Works From Outside the Space-Time Reality

What lurks behind the statistical interpretation is the notion that quantum mechanics is not the final story, but must be supplemented by some kind of hidden variables that operate from behind the scenes and manipulate the fate of single quantum objects, including that of the cat in Schrödinger's paradox. However, Bell's theorem discussed in the last chapter proved that local hidden variables theories are not compatible with quantum mechanics, and Aspect's and others' experiments have verified that local hidden variables theories indeed fail to agree with experimental data, while quantum mechanics does not.

There is also David Bohm's nonlocal hidden variable theory already introduced in the last chapter. Like local hidden variable theories, Bohm starts with the basic idea that quantum objects represent a wave piloting a particle, but unlike local hidden variable theories, Bohm's pilot waves are not physical waves in space-time. Instead they are fluctuating possibility waves in potentia (which Bohm philosophically calls the hidden implicate order) whose average behavior over some characteristic time is given by the Schrödinger equation. The wave guides the trajectory or channel that the particle follows via a nonlocal quantum potential. Bohm avoids the measurement problem (discontinuous collapse of the wave function) because the model forces the particle into one channel in any given measurement situation leaving the other channels (other possibilities) empty.

But Bohm's model already takes us outside the domain of material realism because the quantum potential is nonlocal. The physicist Bernard D'Espagnat has called Bohm's philosophy a nonphysical realism. We will discuss Bohm's theory further in a later chapter (see Chapter 21).

The Copenhagen Interpretation, the Classical/Quantum Dichotomy, and Macrorealism

What does standard Copenhagen interpretation have to say about the cat paradox? Copenhagenists led by the great Niels Bohr himself shied away from the problem and never really much engaged with it. Basically, Bohr's contention was that there is no denying the strangeness of quantum mechanics, but perhaps one should avoid too much controversy with experimental physicists who insist on "calling things as I see them." So Bohr suggested that it is at the measurement apparatus, at the Geiger counter in the case of Schrödinger's cat paradox, that we must assume that the collapse of the dead/alive dichotomy takes place. In other words, the Geiger counter, because of its classical nature, never catches the dichotomy of the radioactive decay of the atom, so the subsequent predicament of the cat is avoided.

The difficulty with this way of thinking is that now we are introducing another dichotomy, the classical/quantum dichotomy, in physics. Implicitly, Bohr is saying that quantum physics applies to micro objects, atoms, and electrons. But large-scale objects like a Geiger counter obey classical Newtonian physics and do not become superpositions of possibilities.

So Bohr is really replacing one dichotomy, the cat's, with another. The correspondence principle—in the limit of large-scale objects, quantum behavior gives way to classical—played a large role in Bohr's thinking. The quantum/classical dichotomy takes the correspondence principle one step further—instead of approximate classical behavior, we are asked to assume absolute classical behavior at the macro level.

Now, nobody likes a classical/quantum dichotomy for the simple reason that it betrays the very philosophical basis of reductionism—micro makes up macro. If micro makes up macro, and micro is governed by quantum laws, it is very logical indeed to think that macro must also obey quantum mechanics, although the effect may be camouflaged.

But Bohr chose to remain slippery on this philosophical issue. So came a new philosophy on the horizon, the philosophy of macrorealism. This philosophy, enunciated by the physicist Anthony Legget, correctly points out that ultimately the issue of classical/quantum dichotomy is an experimental question. So a device called by the interesting acronym SQUID (for **S**uperconducting **QU**antum **I**nterference **D**evice) was developed to experimentally test the question, Do macrobodies really behave classically? Leggett's philosophy is called macrorealism, because it proposes that although the micro domain of nature may be haunted by idealist notions, the macro domain is strictly realistic. Objects in the macro domain have real position and momentum at the same time.

Now there is a small subtlety here. Experiments have directly verified that the center of mass of a macro object does obey the uncertainty principle, and hence quantum physics. In other words, when we don't watch it, even a macro object moves from its trajectory as the uncertainty principle dictates. What Leggett proposes is that maybe the wave function description of relative motion (the motion of microconsituents of a macrobody about the center of mass) ceases to hold for a macro object. In other words, macro objects never become superpositions of possibilities for their internal movement, for their internal states.

So what did SQUID experiments prove? That almost certainly quantum superposi-

tion description holds even for macro objects. The classical/quantum dichotomy does not exist, and macrorealism is a false philosophy!

To its credit, however, macrorealism is a metaphysics conducive to experimental verification or falsification, and therefore is deserving of the attention given to it. The same cannot be said for the two exotic resolutions in the following two sections.

Some physicists have invoked the idea of irreversibility to inject a classical/quantum dichotomy of matter. In the macro world around us, most phenomena are irreversible. What that means is that we do not see the phenomenon going in the time-reversed direction by itself, spontaneously. If a cup breaks, the fragments don't jump up and get back together spontaneously by themselves—this is irreversibility. In contrast, only a few things, such as a pendulum swing, seems to be reversible, and even these phenomena, if you wait long enough become irreversible eventually. In contrast, so long as we are not observing them, that is, quantum movements in possibility seem to be completely reversible.

So it may seem that there is a classical/quantum dichotomy after all. Can we use this to assert that when a quantum system is measured by a macro measurement apparatus, the wave function of the quantum system collapses because the behavior of the macro system is irreversible? Alas! This argument does not work because the classical equations of movement, including Newton's second law of motion, do not change either when we change the direction of time, just like Schrödinger's equation of quantum movement. The time-irreversibility of the classical macro world is only appearance. The appearance is created by the extremely small probability that exists for a disorderly system in its final state (such as the cup fragments resulting from the breaking of a cup) to get back to its initial order (the whole, unbroken cup). If we wait long enough, however, such an unlikely event as cup fragments leaping up spontaneously and joining together can and must happen, according to Newton's law.

So some physicists, most notably the Nobel laureate Ilia Prigogine, are willing to break with Newton's laws and introduce new equations of movement that would make the classical world truly irreversible. These physicists note that there is no *a priori* reason for matter to follow laws such as Newton's. The idea of laws is a holdover from idealist thinking like Plato's (see Volume I). In order to be consistent, these physicists even suggest that the irreversible equations of movement of matter should follow from the movement of matter itself at the base level. If this could be validated, then, of course, we would have a completely consistent theory of material movement based on material realism. But so far, the validation is lacking. More on this subject in Chapter 25.

The Many Worlds Theory: Discontinuous Collapse Is Not Needed Because Everything That Quantum Mechanics Predicts Is Seen in One of Many Parallel Universes

The many worlds theory, as the name suggests, is the idea that there are many parallel worlds, and in the event of a quantum measurement each of the possibilities calculated

from quantum dynamics is manifested in one of these parallel universes. Thus, in this view, when I open the box to find Schrödinger's cat alive, a prototype of me in a parallel universe opens the box and finds it dead. In an earlier version, the first one due to physicist Hugh Everett in 1958, in the event of every quantum measurement, the universe splits so that every possibility is realized in one of the split branches.

The many worlds interpretation has become popular because starting with Philip K. Dick, science fiction writers increasingly use parallel universes in their story lines. In Dick's 1962 novel, *The Man in the High Castle*, a post-World War II reality is described in which Germany and Japan have won the war and are occupying the United States, except for a buffer zone around the Rocky Mountains. An author in this buffer zone has written a book depicting a different reality in which the United States and the allies have won the war. The plot becomes increasingly interesting as some of the characters find themselves jumping in and out of both realities.

The parallel universes of the many worlds interpretation of quantum mechanics are, however, truly parallel. That is, they do not interact in any local way. As a local being, as a brain, I cannot verify that I am getting one knowledge in this universe and a different knowledge in another universe. Of course, you can also wonder how we can get all these different knowledges from our various quantum measurements (every act of perception is a quantum measurement, isn't it?) and still be called the same observer, as science fiction story lines would demand.

One major criticism of the many worlds theory comes from the principle of parsimony, a principle that is also called *Occam's razor*, according to which a theory should be economical in its assumptions. Instead, many worlds theory is infinitely extravagant in proposing infinite number of parallel universes as a solution to the quantum measurement problem. Even bigger criticism, and the crucial one, is that the theory is impossible to verify or falsify.

The many worlds theory also has a conceptual flaw. Go back to the double-slit experiment and try to apply the many worlds argument for quantum measurement there. An electron goes through a double slit arrangement and becomes a superposition of two possibilities, which then interfere giving rise to an interference pattern on a fluorescent screen. In the first case, the electron's interaction with the double slit, the universe doesn't split; but when the electron interacts with the fluorescent screen, the universe does split and along with it the electron. But how does the electron know when to split and when not to split? All it is doing is interacting with atoms in both cases.

And if you say that when the electron goes through the double slit it does split, as does the universe, each of the universes having an electron going through only one slit, in order to explain interference you must also postulate that the two universes fuse together again. However, when we attempt to see which slit the electron passes through, then the electron passes through only one slit in this universe and through the other slit in a parallel universe and the universes do not fuse together again. The question is, How do the universes know when to fuse or not to fuse?

The crucial question then is how to decide what defines a measurement situation. This flaw was first pointed out by the physicist Euan Squires who then formulated his "many viewers theory," where the existence of a viewer differentiates between a situation when there is a measurement (and when realization takes place in parallel universes) and

when there is no measurement and interference can happen. But in the realist view, there is nothing special to the viewer, a viewer is just another conglomerate of matter. If we make the viewer special, we are really assuming some kind of dualism, matter with consciousness different from matter without consciousness.

Transactional Interpretation: The Discontinuity of Quantum Collapse Is Only Appearance—There Is a Mechanism Behind It

There is an electron in the room and it is spreading all over. You want to detect it and you have set up a roomful of Geiger counters. You activate the counters. Which one will detect the electron in a given measurement? University of Washington physicist John Cramer says that the counter that is situated at the location where a wave from the future, a backward-going possibility wave (which mathematically is the "conjugate" wave to the electron's possibility wave) meets up with the electron's forward-going (in time) possibility wave is the one to get the nod. That is where the electron is going to collapse. In Cramer's view, collapse is nothing but the multiplication, you can think of it as a modulation, of a possibility wave and its conjugate. (This part is cute: mathematically speaking, indeed possibility times conjugate is reality—the probability for finding the object in that place!) The collapse may seem to be discontinuous, but underneath there is a rational explanation, a mechanism, after all, and realist thinking is reestablished!

It is true that you have to change your notions of causality a bit. In your ordinary perception you think that the electron is a signal that the detector detects. In Cramer's description, the measurement is a mutual "handshake," a transaction, completed between the electron's wave (which Cramer calls an offer wave) and the wave from the future (which Cramer calls an echo) that the detector extends (waves backward in time converge onto the source). And you cannot tell which wave was causally first—which caused which!

What is a backward-going (in time) possibility wave? The idea of forward-in-time possibility waves, the ones we have been using to describe quantum objects, makes sense because there are in nature classical waves that fit the description, the waves that you see around you. Unfortunately, nobody has ever seen a wave going backward in time, a wave that suddenly arrives in the boundary of your swimming pool, contracting and collapsing to the center where you threw a pebble.

So Cramer's transaction theory has not gotten much attention because it makes an *ad hoc* assumption of something that is impossible to verify. On top of that, the idea is too mathematical to use in science fiction.

You can also see the same kind of flaw in Cramer's theory that haunts the parallel universe theory. What is so special about a detector (which is just another quantum object, just a conglomerate of atoms, and therefore, itself only an offer wave) that there should appear a backwardly traveling conjugate wave there in a measurement situation, that it should be able to give out an echo wave to an electron's offer wave? If we say that the detector is special, it is not quantum, we are invoking the classical/quantum dichotomy once again. If we say that an observer's intention is what makes the echo wave possible,

then lurking behind the theory is an intending observer and a dualism. The physicist Fred Alan Wolf sees this quandary very clearly and he extends Cramer's theory to very clever scenarios in his books by including the conscious mind (read his books *Parallel Universes* and *The Spiritual Universe*), but he cannot shake the criticism that waves backward in time are *ad hoc* and that there is implicit dualism.

In Summary

The various proposals to resolve Schrödinger's cat paradox, or what is really the quantum measurement problem, make one thing very clear. None of the solutions get rid of quantum weirdness; it is like replacing one weirdness with another. Moreover, in all the theories, consciousness–an observer–lurks behind implicitly; there is an implicit dualism. (Even David Bohm's theory, when we examine it carefully, does not rid of a conscious observer. See Chapter 21.) So we may as well invite consciousness into the affairs of the quantum (see Part 5) and explore if, in a consciousness-oriented thinking, we can get rid of dualism! But first we will make a detour and review some recent ideas about how consciousness may emerge in the brain itself if the brain is quantum!

Bibliography

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Putnam/Tarcher, 1993.

Wolf, F.A. *Taking the Quantum Leap*. San Francisco: Harper & Row, 1981.

Wolf, F.A. *Parallel Universes*. NY: Simon & Schuster, 1988.

Wolf, F.A. *The Spiritual Universe*. NY: Simon & Schuster, 1997.

CHAPTER 16

Speculations About the Brain: Consciousness Within the Quantum

Many people view themselves merely as classical computers, albeit working through biological elements—the neurons of our brain—with interconnections that boggle the mind. People are very different from the silicon computers we build. Nevertheless, the brain is widely thought of as a sort of a classical computer. And in this view, consciousness is like the central processing unit (CPU) of the brain's computer.

So the first question is, Can we identify a physical location in the brain that is the analog of the CPU in a conventional computer? The brain is viewed by brain scientists in many different ways, but one way is to view it as three concentric shells (Figure 16.1). The uppermost shell is the site of the cortex. The structures below are classified as the basal ganglia, the limbic system, and the hippocampus. The innermost shell is the centrally located thalamus. These three shells are symmetrically split into the left and right hemispheres; so there are left and right cortices, left and right subcortical areas, and left and right thalamuses. All the three shells straddle the brain stem, which is unpaired (that is, not divided into left and right hemispheric elements) and which itself is an outgrowth of the spinal cord.

One candidate for the brain's CPU is the two thalamuses because, as even the great Descartes thought, the command center of the brain should be centrally located. Indeed,

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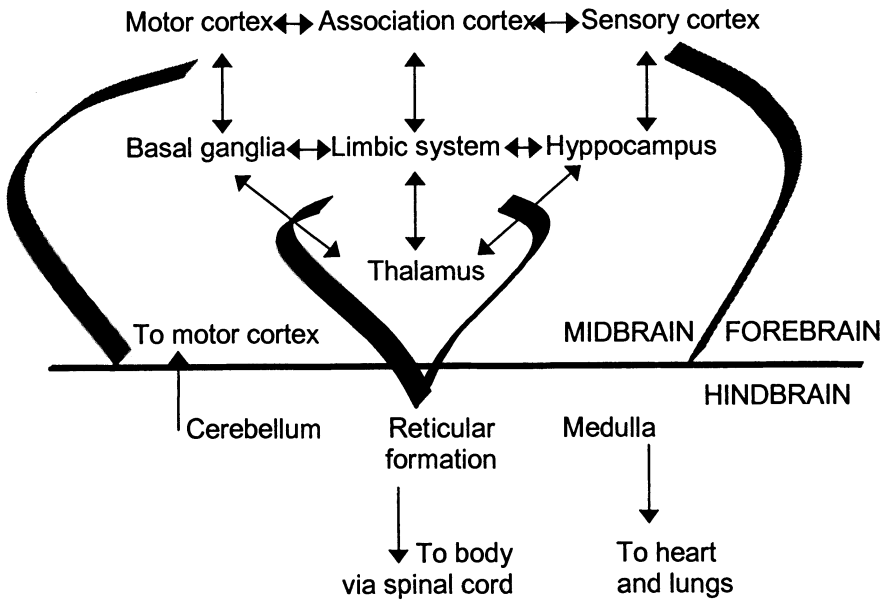

Figure 16.1
Different scientists view the brain differently; one way is to see it as concentric shells.

the thalamuses may have some integrative functions: most senses (except smell) are channeled through the thalamuses, as are most of the body's motor signals. However, more likely the two thalamuses can be seen as the brain's central relay stations, nothing more.

Deep in the brain stem there is another structure, called the reticular formation, which has the support of many brain scientists to be the CPU. It satisfies Descartes' criterion—it is centrally located as well. Moreover, to its advantage it is a unique structure, not paired. Like the thalamus, it also straddles the major sensory and motor neural pathways. In addition, the reticular formation seems to be the "guardian" of what happens to the organism, both in its motor aspects and its sensory aspects. In other words, without the activation of the reticular formation, there is no decision making as to whether the organism should fight, flight, run, sleep, or speak, or what sensory input the organism should attend to. From this, one is tempted to conclude that the reticular formation is the decision-maker—the seat of consciousness.

Indeed, studies of coma and cerebral concussion have shown that the brain stem (which includes the reticular formation) is essential for the maintenance of awareness itself. Also, drugs (such as LSD) that modify consciousness—the conscious identity of who you are—act on the brain stem.

All these things fit. Unfortunately, there is no identified mechanism, no area in the reticular formation, where the performances of the various brain parts (mainly cortical areas) during a particular task are brought together and integrated. One can explain whatever the reticular formation does as simply the action of an on/off switch. It is essential that this organ be "on" but studying it will teach us nothing about how the CPU of the brain works.

If we give up the idea of central location, then obviously the cortex itself should have an area where the highest brain function—integration of what the various parts are doing—should take place. The cortex is divided into three areas: motor, sensory, and the rest of it, which is called "associational." Perhaps somewhere in the associational area is the place that marks the boundary of the self. But the work of the famous Canadian neurosurgeon Wilder Penfield seems to rule out the idea.

Penfield electrically stimulated (by means of electrodes inserted into the cortex during brain surgery since no pain is involved) more than a thousand patients to listen to the subjective reports of such experiences. Indeed, some of his patients described the arousal of amazingly vivid memory, so the contents of consciousness could be changed by these manipulations, no doubt. But Penfield was never able to activate any area that changed the patient's sense of the self, the context of consciousness. So Penfield finished his life becoming more and more convinced of a dualism—that the source of "I," consciousness, must be an entity outside the brain, or even outside the whole body.

The criticisms of dualism you already know (see Chapter 2). Perhaps we should look for a different approach to consciousness, one that avoids the idea of a CPU.

Consciousness and Interconnectedness

I read long ago a fictional conversation between God and a human written by an author belonging to the class that I call material realist, but still sympathetic to spirituality. One line in the article stood out for me in which God asks the human being, "Where does the universe end and you begin?"

What is the author trying to say? That there is no such thing as an isolated you, isolated from the rest of the universe. We are all interconnected. But this kind of interconnectedness has a fatal limitation. It is conveyed through local interactions, through electromagnetic forces mainly, going from you to somebody else through space, taking a little time because of the finite speed limit imposed on the propagation of all fields of force by the laws of Einstein's relativity.

I suspect that this model of interconnectedness is not entirely satisfactory to most of us. Imagine your loved one being an astronaut on the moon. Imagine you are looking at the moon and having an intense feeling of interconnectedness with your lover. Do you seriously think that he or she will get that feeling after the time it takes for local interactions to reach there (even if they could)? I think the feeling would be an instantaneous one, simultaneously felt by both of you, not one that is carried by classical, local means.

If you think about it, interconnectedness has to be an affair of our consciousness. There is a wonderful episode of the TV show *Star Trek*, the original series. A fellow has committed a crime for which he has to be punished. But there is no violent punishment in that futuristic society. The writers conceive of a very subtle punishment. The man is banished to an isolated island. But hear this—he will be in the company of many beautiful women. How is this punishment then? There is a catch: the women are all androids, machines.

I submit, as the writers of *Star Trek* well knew, that the interconnectedness that we

feel with other humans, a feeling that we call love, is due to our connection via consciousness that we all share. We are interconnected because consciousness is nonlocal. (Perhaps you are puzzled that with nonlocal consciousness the convict in the *Star Trek* episode needs humans nearby in order to avoid loneliness. Nonlocal consciousness is felt at a distance only when we are correlated with another human being, such as when love already exists—then only are distances transcended. Without a loving relationship's already existing, we need proximity triggers and mutual intentions to create new love relationships!)

How do we then make a scientific model of consciousness? The physicist Richard Feynman showed long ago that a classical machine (such as our silicon computers) can never simulate quantum nonlocality. So if the brain generates consciousness, as we must agree as long as we stay within a material realist model of the world, and if we think of the brain as a classical computer, we are stuck. Our theories of the brain are never going to encompass its most exciting property—interconnectedness.

Enter a class of brilliant theorists of the new age in the tradition of *The Tao of Physics*, but philosophically more astute. They clearly see the limitations of the Tao-of-physics thinking with classical models, be it based on complexity or chaos theory, the locality of all classical systems. Local interconnections do not reach out instantly. We must, these theorists argue eloquently, give up classical modeling for the brain. Why can't we think of the brain as a quantum machine? Why don't we?

The advantage of such an approach is clear. As a quantum machine, the brain has to be nonlocal. Then consciousness as a quantum brain phenomenon can also be nonlocal.

How can a macrosystem like the brain be quantum? Well, first of all, it is a fact that the brain can respond even to a single photon. This is suggestive that maybe the brain as a whole engages as a quantum system with the photon. Second, there is the famous problem called the binding problem in neurophysiology that has to do with the unity of our conscious experiences. In any conscious experience involving the brain, disparate brain areas are involved, neurons sometimes removed from each other by several centimeters. How does the brain bind together these disparate neural activity into a coherent holistic experience in view of the relatively low speed of neural communication? This binding problem is easily explained with the quantum brain hypothesis as an example of quantum nonlocality. Third, there are many examples of quantum-like behavior of thought. For example, if I say an ambiguous word, you have the capacity of responding in many different ways. If the mind corresponds to classical brain processes, this multiplicity of response is not easy to duplicate. But in the quantum picture, we can readily see that the brain goes to a state of superposition of possibilities in response to an ambiguous stimulus out of which a particular response is selected.

The next problem is to produce a model for the macro quantum brain considering that, in view of the correspondence principle, macrobodies are expected to resort to the classical limit. But the physicist has a few examples of quantum behavior even at the macro level. One such example is the superconductor, a substance, usually at a low temperture, that can carry an electric current without offering resistance. A superconductor is quantum because there are correlated pairs of quantum objects in it (called Cooper pairs) that, because of their correlation, are able to dance with one another at a distance, maintaining macroscopic phase coherence. Why can't the brain have analogs of Cooper pairs?

There are problems with this idea: the high temperature of the brain for one, but suppose it works out in some way. What then? Can we not theorize that such a coherently functioning quantum brain is also conscious, that consciousness is a fall-out, a consequence of the brain's quantum nature?

This is the minimum model. Once we get the basic idea, we can play many variations on it. Let us examine some representatives of these "quantum theories of consciousness." I call these "consciousness-within-quantum" models, because in all of these models consciousness is secondary to the brain; it arises from the quantum nature of the brain. A good review is available in physicist Nick Herbert's book *Elemental Mind*.

About Neurons

But first we need to review the neuronal structure of the brain just a bit. Figure 16.2 shows a neuron. As cells go, it is a long cell. It has many incoming branches (these are the dendrites), but only one output line (called the axon). The cell body out of which the dendrites and axons grow contains the cell nucleus and the metabolic machinery—the energy source for the neuron's activity, especially the electrical activity. It is the conglom-

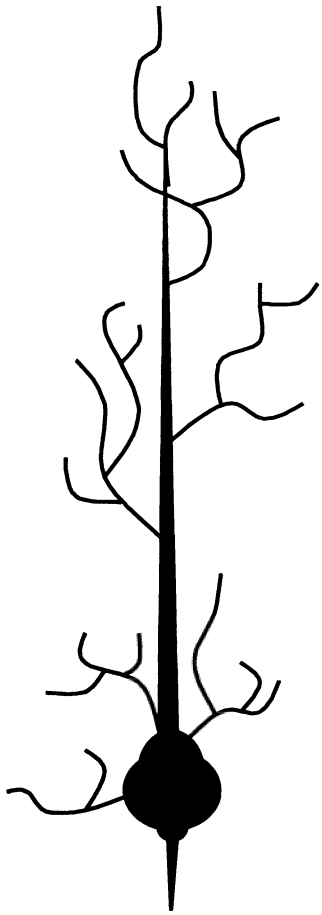

Figure 16.2
A typical neuron in the neocortex.

erate of these cell bodies that make up the gray matter of the brain and the spinal column.

Now all the cells of our body are potentially batteries. The difference of electrical potential energy (what you call voltage is electrical potential energy difference per unit electric charge) that empowers the battery comes from the difference in concentration of sodium and potassium ions across the cell membrane. In most body cells, the battery function remains latent, but in the neurons, local changes in the battery voltage make possible the propagation of electric signals along the dendrites and the axon.

Let's now try to understand the propagation of a nerve impulse with which the brain carries out its computational activities, and also communicates with the sense organs and the muscles. When a part of a nerve cell battery is discharged, say, by an electrical, chemical, or mechanical external influence, the tendency of the cell is to return to its normal voltage rather quickly. But the situation changes if the external influence is insistent and the resulting discharge is intense and/or takes place for a long time. Then the nerve cell does not bounce back to its normal voltage. Instead its battery discharge triggers battery discharges in neighboring regions of the cell membrane, which in their turn trigger battery discharges in regions of the cell membrane a little further away, and very soon we have a wave of electrical discharge, a nerve impulse, along the membrane of the neuron. Of course, after the discharge wave has passed, sometimes in its wake, the neuron gradually comes back to its normal voltage.

Now comes the question of communication between one neuron and the next; this is where things get really interesting. A neuron never physically touches the next neighbor with its dendrites. Each neuron is separated from its neighbor by a small gap called the synapse, which is large enough to prevent the transmission of the weak electrical signal across it. So the synapse acts like a currency exchange: it changes electrical stuff into chemical stuff. The electrical discharge on one side of the synapse induces the emission of neurotransmitter substances that quickly diffuse across the watery gap to the other side of the synapse into the next cell. There the neurotransmitter chemicals either induce discharge (for an excitatory synapse) or suppress it (for an inhibitory synapse). So what happens at a synapse is a conversion of an electrical signal into a chemical one and reconversion back into an electrical one.

Some of the names of these neurotransmitters you will recognize: dopamine whose imbalance is associated with schizophrenia: serotonin, whose balance is connected with sleep and relaxation, and so forth.

The electrical signals produced by the neurotransmitters in the adjacent cell now travel along the dendrites to the cell body proper, adding up to a larger composite signal. Then it's a question of reaching a threshold. If the composite reaches above a threshold voltage, the new cell fires sending a nerve impulse along its axon. If the composite signal voltage fails to reach the threshold, the nerve axon does not fire. This nerve will be out of commission from all the communications going on in its neighborhood.

There is a computer element called the n-input AND gate where n-input signals join together to produce an excitatory or inhibitory response. A neuron with n synapses is a similar beast with one interesting difference. The behavior of the AND gate is determined—the same input always produces the same output response. Not so for the neuron. Besides the electrical input, there are many other factors that influence the neuronal response. Some of these, such as the previous history, are known. Some are as yet unknown.

In other words, there is uncertainty in the behavior of the neuronal AND gate; so with some justification the computer scientist Ernest Kent calls them MAYBE gates. Now you can see why this may be exciting to a quantum physicist. Perhaps one of the factors that influences the "maybe" behavior of the neuronal gate is the "maybe" of the quantum uncertainty principle itself.

There are other ways also that one can envision quantum effects in neuron dynamics. One of these ways, developed by the psychologist Ian Marshall, has been used with considerable poetical skill as a metaphor for self-consciousness by Marshall's wife, the philosopher and author Dana Zohar. Let's discuss Marshall's and Zohar's work.

Does Self-Consciousness Arise from Quantum Coherence of the Brain?

Beside the superconductors, there is also the phenomenon of large-scale coherence called boson condensation, which is responsible for frictionless flow in superfluids, for example, in liquid helium at very low temperatures (close to absolute zero). The helium molecules at very low temperature become correlated via their interactions and are able to "condense" in the same quantum "ground" state. All the molecules then move coherently, as if they were one body—one macromolecule. And because of the coherent movement, all the resistance to the flow, which is due to random collisions between parts, disappears.

Is there a collection of coherently oscillating molecules in the brain? There are arrays of protein molecules within the membranes surrounding the nerve cells that are linked by electrical interactions. Just as a tuning fork vibrates to give off sound waves, the linked oscillating proteins of a cell membrane can be thought of as exhibiting a wave motion pumped by the energy of thermal and biochemical processes. However sound waves are normally classical movement. But suppose the motion of the sound waves of the oscillating proteins is quantum. This requires certain special conditions to be satisfied by the system. Suppose they are all satisfied. What is the advantage?

The advantage, of course, is the possibility of Boson condensation. If the waves move classically, any energy that is supplied to the system (by the chemical processes responsible for the propagation of nerve impulses) will go to individual waves, which will be moving in their separate, random ways. In contrast, if the waves move the quantum way (such quantized sound waves are called phonons), then it is possible that they will partake any energy supplied as one body, in unison. This then will provide us with the unity of brain functioning that we are looking for, the oneness of a conscious experience.

So Marshall and Zohar theorize that in any conscious process, all the different individual neurons in different brain areas that are involved are doing a collective quantum dance from which rises our self-experience. Zohar calls this self-experience the quantum self. Zohar is quite poetic about this quantum nature of the self:

> There is something deeply feminine about seeing the self as part of a quantum process, about feeling in one's whole being that I and you overlap and are interwoven,

> both now and in the future. Selecting things out, seeing them as separate, naming them, and structuring them logically are male attributes. They follow, if you like, from the "particle aspect" of our intelligence. Seeing the connections between things is more feminine. It mirrors the "wave aspect" of the psyche.

When Newtonian particles meet, they collide and go their separate ways (Figure 16.3a)); this is what takes place, according to Zohar, when we encounter one another with the male aspect of our selves. On the other hand, when two brains meet in their wave aspect, in their quantum-self aspect, the two brains become one system when their waves overlap (Figure 16.3b)).

In another way of looking at it, when we see brains, the collapsed quantum objects look separate and individual. We are seeing the "matter" aspect of the brain. But when there is no collapse, the brains can co-mingle in their wave aspect. This is what we experience as the psyche, as consciousness, according to Zohar. This is the "mind" aspect of the brain. Long ago, the philosopher Baruch Spinoza formulated the double aspect theory as

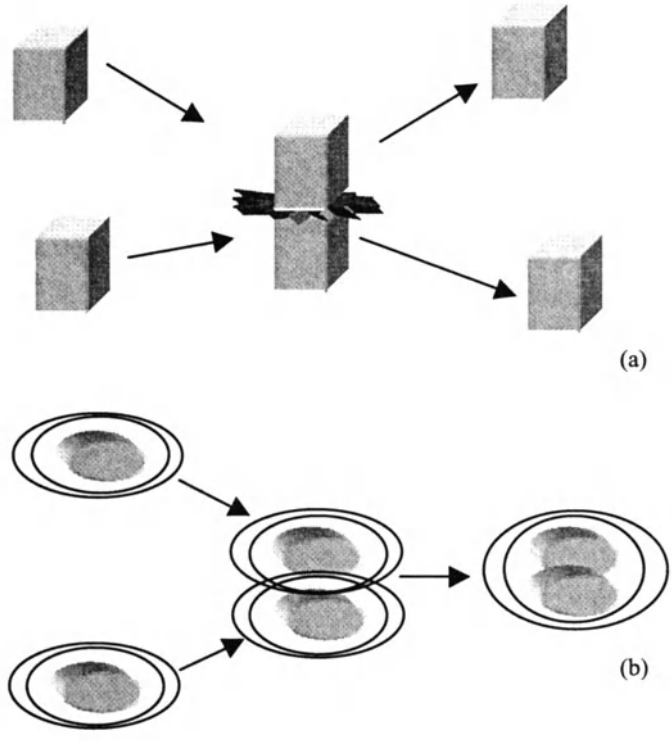

Figure 16.3
(a) When Newtonian particles meet, they collide and go their separate ways; this is what takes place, according to Zohar, when we encounter one another with the male aspect of ourselves.
(b) When two brains meet in their wave aspects—in their quantum self-aspects—the two brains become one system when their waves overlap.

a solution to the mind-brain problem—mind and brain are two complementary aspects of the same thing. Zohar seems to be siding with Spinoza when she talks about matter and mind aspects of the brain.

This is a wonderful metaphor for love, but unfortunately there is a conceptual flaw in this kind of picture. The quantum coherent waves of the brain are all confined standing waves (like the electron waves inside an atom). They do their waving in place; they don't spread out in space and overlap with other external waves. And if you think that these waves can mingle when the brains as a whole spread (after all, there is no such thing as a classical object; so the center of mass of the brain must exhibit some wave functioning, that is, they must spread in time when nobody is watching), think again. Brains are quite massive; for the center of mass of two brains to spread in possibility and mingle takes billions of years.

The verdict? Even if the brain acts as a Boson condensate for its internal movements, we cannot envision all the wonderful quantum properties of interconnectedness that we attribute to consciousness. We have to look for other alternatives to envision the relation of the quantum nature of the brain and consciousness if we are to capture interconnectedness as a fundamental property of consciousness (which it is).

I have mentioned the idea of holographic consciousness before (see Chapter 9). The former astronaut Edgar Mitchell has taken this holographic model further by proposing that every object, micro or macro, is a "quantum hologram." By that, what is meant is that the quantum movement of the components inside every object in the universe is somehow coherent, and the object's total wave function carries information in the phase relationships of its component waves of possibility. Our brain, likewise, is a hologram, and when the object's wave function expands to mingle with that of the brain, the brain decodes the information. The resultant feedback results in perception. However, the criticism above to Zohar and Marshall's model also applies to this one. It takes the possibility wave of a macro object billions of years to expand sufficiently to mingle with that of another even close-by object. Perception through local means of electromagnetic signals occurs long before that.

Quantum Gravity in the Brain?

The mathematician Roger Penrose sees consciousness arising from the quantum nature of the brain—in fact, from the event of collapse of the wave function of the quantum brain, but only in conjunction with a new theory of space-time structure that he calls quantum gravity. In this way Penrose tries to connect three very difficult scientific problems: the problem of consciousness, the problem of quantum collapse, and the problem of quantizing gravity.

Let us look at a key aspect of consciousness according to Penrose. How does a mathematician solve a problem of mathematics? Penrose argues that the mathematician does not necessarily follow algorithms, the step-by-step procedure, like a computer, but instead directly sees the validity of a solution. There is a theorem in mathematics called Gödel's incompleteness theorem, discovered by Princeton mathematician Kurt Gödel in the 1930s. According to this theorem, there are certain propositions (Gödellian propositions) in any

sufficiently elaborate mathematical system (the number system is an example) that cannot be proven algorithmically (or disproven) staying within the system, so all mathematical systems are incomplete. But, argues Penrose, the mathematician can see the validity of the proposition directly, thus suggesting that doing mathematics, a conscious task, must be, in part, nonalgorithmic. It follows that consciousness itself must then be nonalgorithmic.

Actually, Penrose's proofs are controversial, but I doubt if anybody can argue with the idea that creativity (including creativity in mathematics) is in part nonalgorithmic. Thus, in its creative aspect, consciousness has to be nonalgorithmic, unlike a machine. Since Penrose is a material realist, he has, however, no doubt that consciousness is a brain phenomenon. It follows, then, that for Penrose part of the brain functioning must be nonalgorithmic. The brain cannot possibly be explained by Newtonian classical algorithmic physics.

What is the obvious candidate for something nonalgorithmic in the brain? Quantum collapse, of course. Nobody can deny that brain plays a role in any measurement or collapse of a quantum system. No measurement can be discussed without considering the quantum mechanics of "seeing" by a conscious observer and thus, this collapse must involve, according to Penrose, an objective reduction of quantum superpositions of possibilities in the brain in response to the system. When such a reduction occurs, there is consciousness.

The third tier of the argument is very complex and I won't go into details. Basically, Penrose says that the macroscopically superposed quantum possibilities of the brain come with superposed space-time geometries. The theory of quantum gravity determines the scale at which these superpositions of space-time geometries become unstable and self-reduce to a single universal state, which is consciousness.

So again, a crucial question is, Can the brain, does the brain, have macroscopically distinguished superposition of possibilities that are sustained until the appropriate threshold of mass-time-energy related to quantum gravity is reached? Here together with the neurophysiologist Stuart Hameroff, Penrose has suggested a mechanism.

According to Penrose and Hameroff, there is only one neuronal substructure that satisfies all the desirable criteria for the brain's quantum system. This is the microtubule structure. A microtubule is a hollow cylindrical polymer of individual proteins called tubulin, and is the major component of the self-assembling protein network called the cytoskeleton that organizes the interior of all living cells, including neurons. Microtubules have a high degree of presence in the neuronal structure. They have important known functions: they regulate the connection between neurons and synaptic functions. They are somewhat isolated from the cellular environment, thus preventing decoherence. They are small enough to be coupled to the micro quantum level events in the brain. They are hollow and cylindrical, making them suitable as wave guides used in electromagnetic wave propagation. They are even considered suitable for information processing.

Each self-organized collapse of the brain's macroscopic coherent superposition is seen as one conscious event, and a cascade of such events, then, give rise to the stream of consciousness of our experience. Because of quantum states' being nonlocal, the binding problem is solved, which is true of the Marshall/Zohar model as well. However, in addition to the problem of consciousness, here the previously unsolved problem of quantum collapse is also solved, staying within material realism. The shortcoming of this approach

is the linking of quantum gravity, the theory for which is highly speculative—should the linking of quantum theory and Einstein's theory of general relativity be impossible to achieve within conventional algorithmic tracts? By itself, this should not look so bad, but when one combines three speculative ideas, namely, that consciousness is a brain function, that a nonalgorithmic theory of quantum gravity makes sense, and that a material realist theory of collapse is possible, then the theory becomes less believable. It's like Penrose posits three possible candidates for which no algorithmic solution is in sight and forcefully links them together by wishing it so. On top of this, the idea that the brain has a macrocoscopic quantum structure in the macrotubule network is also highly questionable, and rumor is that Penrose has since withdrawn his endorsement of this idea.

Ultimately, all of the theories discussed above, and more generally, all materially based (that is, brain-based) theories of consciousness have one ultimate difficulty and shortcoming. They do not, they cannot address what the philosopher David Chalmers calls "the hard problem" of consciousness. This is the problem of deriving subjective, felt experience (technically philosophers refer to this as "qualia") starting with objective mechanisms. In computer jargon, if you start with one input (the object), you end up with one output (also object); you can never produce the experience of a subject looking at an object. And yet this subject-object split that we call awareness is a fundamental aspect of our consciousness. All theories of consciousness must address this hard question.

Bibliography

Herbert, N. *Elemental Mind.* NY: Dutton, 1993.

Hameroff, S., and Penrose, R. "Conscious Events As Orchestrated Space-Time Selections," *Journal of Consciousness Studies*, vol. 3, pp. 36-53, 1996.

Zohar, D., and Marshall, I. *The Quantum Society.* NY: Quill, 1994.

Part FIVE

QUANTUM WITHIN CONSCIOUSNESS

CHAPTER 17

Consciousness Enters Physics

If physics cannot explain consciousness, then can consciousness explain physics? It is a fact that quantum physics, in spite of all of its spectacular successes, bogs down when the fundamental question of quantum measurement is asked: Who or what collapses the quantum wave function? Who or what makes actuality out of mere possibility? Is consciousness the answer to this million-dollar question?

In classical physics, consciousness is not needed. The algorithms of classical physics give us the complete answer for the movement of its objects—where an object is when. The algorithms are closed and the movements of objects are determined. But the deterministic algorithms of classical physics, closed as they are, do not agree with experimental data in the microrealm of matter. For agreement with experiment, we need a quantum physics description of objects. In quantum physics, there are algorithms, there is determinism, but only to a degree. Quantum algorithms do not tell us where an object is when, exactly, but only point to the possibility of where it may be when, with what probability. This probability calculus is fine so long as we deal with a large number of objects or large number of events (or both), which is what we do in laboratory physics and chemistry. But when we are dealing with single systems, as in the living and conscious systems of biology and psychology, the question of how actual events come about from the possibilities cannot be avoided.

Even without the consideration of biological systems, the question of closure of quantum algorithms is a thorny one that material realism cannot solve, as discussed earlier (see

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Chapter 15). We cannot do quantum physics without complementing the notion of continuous algorithmic predictable movement of quantum objects—the time-development of the waves of possibility—with the idea of discontinuous, nonalgorithmic, unpredictable event of collapse of the wave of possibility due to measurement.

Then there is the question of subject-object mixing that Bohr's idea of complementarity focuses upon. Recall what complementarity says: the wave and particle aspect of a quantum object are complementary, we can measure only one at a time with a given experimental arrangement. But if this is so, we have the choice to bring about the particle aspect or the wave aspect when we deal with quantum objects by choosing the experimental apparatus we use. We seem to have an essential role in how reality manifests.

Notice the parallel of Bohr's complementarity lesson with Zen teachings. Zenmaster Baso is asked by a monk, "What is Buddha?" "This mind is Buddha," answers Baso. But when a second monk asks the same question, "What is Buddha?" Baso answers, "This mind is not Buddha?" Baso is teaching his disciples about mind, about the nature of consciousness. There it makes sense to create ambiguity in consciousness, because the spiritual quest is to uncover the play of consciousness. Is the ambiguity of the quantum object similarly a guide to the play of consciousness?

Who or What Collapses the Wave Function?

Does consciousness collapse the quantum wave function? Is the discontinuous event of quantum movement in quantum physics, the event of collapse, a play of consciousness as well? The mathematician John von Neumann was the first to be daring enough to think so. Von Neumann is famous for putting quantum mechanics on a firm mathematical basis. The dancing Wu Li masters of physics such as Werner Heisenberg and Paul Dirac danced their way into making new choreography, new mathematics, for exploring the quantum—but alas! Often their ideas lacked mathematical rigor. Von Neumann provided the rigor.

When von Neumann came across the quantum measurement problem, he looked at it from a mathematical point of view. Can one ever find an explanation of discontinuous collapse of the wave function within quantum mechanics? No, said von Neumann. Quantum mechanics only permits continuous transformations, called "unitary" transformations. Superpositions of possibilities remain superpositions under unitary transformations; they don't reduce to an actuality.

Coupling a measurement apparatus to a quantum system enlarges the system and its possibility structure, but the idea of superpositions' remaining superpositions persists. We can couple another measurement apparatus to "measure" what was before, but the conclusion is the same. We get a bigger structure of possibilities. Indeed, said von Neumann, if we send an infinite number of measurement apparatuses, even then the system and all these measurement apparatuses will remain in limbo, as quantum possibilities. This is called the problem of infinite von Neumann chain that cannot collapse of itself (Figure 17.1).

Alas! A "measurement" apparatus cannot measure. How can it, because it is also a quantum system, itself made of atoms, electrons, and such—quantum systems all? One,

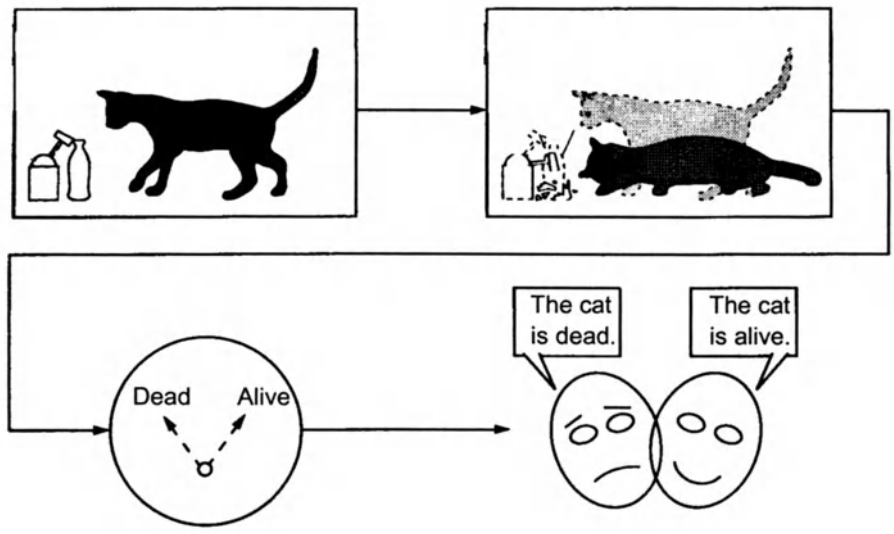

Figure 17.1
The von Neumann chain. Following von Neumann's argument, even our brain-mind catches the dichotomy of the cat, so how does the chain terminate? (Reprinted from A. Goswami, *Quantum Mechanics* with permission from William C. Brown/McGraw Hill.)

which itself obeys quantum mechanics and is a possibility wave, cannot reduce the possibility wave of another. (What does a measurement apparatus do then? What is its usefulness? Its job is to amplify the micro signal of the quantum system into a macro one that we can see. And also, to make a record. What physicists call a measurement apparatus is really a measurement aid apparatus when it comes to quantum measurement. See later.)

What can do the job of collapsing the quantum wave function? We have to jump out of quantum systems and quantum mechanics to find an agent that can collapse the wave function. Von Neumann thought that consciousness is such an agent. A nonmaterial consciousness that does not obey the laws of quantum physics, that transcends the space-time-matter-motion world altogether, collapses the quantum possibility wave into an actual event.

It makes sense. Heisenberg said that the wave function represents not the real system, but our knowledge of the system; and the collapse of the wave function is really a change in our knowledge of the system as a result of measurement.

Heisenberg's idea will seem a little vague until you realize what our knowledge is about. Knowledge is about our facility that knows—our consciousness. Indeed, how can we talk of possibilities without considering something that weighs the possibilities? Possibilities make sense only when they are possibilities of our consciousness, possibilities of our knowledge of the system. Who chooses among the possibilities? Consciousness does, through the act of observation. This is what von Neumann is saying.

Behold! Von Neumann's argument is foolproof. Consciousness is a sufficient condition for collapse because, obviously, whenever we look, whenever we observe, we find actuality, never possibility. We never find an electron in two different places at once. It always appears in one place in our measurement. And consciousness is also a necessary condition for collapse, because material apparatuses cannot do the job. Something non-

material, something connected with knowing, has to do the job. The name of this entity is consciousness.

If consciousness is both necessary and sufficient for the event of collapse, then consciousness has entered physics, subjectivity seems to have entered what is supposed to be objective science. Is this situation tolerable?

Physics is a description of reality. Now, reality that, usually, we study through experience, consists of both subjective aspects and objective aspects. In the past, under the aegis of religion, we used to put overemphasis on the subjective, on being, especially on an ultimate Being (popularly called God). Whenever something of the so-called objective, outside world wouldn't fit, we would invoke this Being. When then-known science was unable to explain a phenomenon (for example, a meteor shower), we would invoke the God-principle. Now we tend to do the opposite. When we encounter a subjective feeling that defies objective explanation, we invoke promissory materialism—there must be a material explanation!

According to some thinkers, the quantum measurement problem becomes a problem because we are taking the dichotomies raised by quantum physics seriously; we are confusing reality with products of our methodology used to assess reality. Could it be that the wave of possibility in quantum physics is a creation of our faulty methodology, of our psychological and neurological mechanisms, and has nothing to do with reality? In this and similar views, this philosophy of instrumentalism—that science is not the investigation of reality but only an useful instrument to sort out data and guide experiment—is invoked whenever a basic tenet of material realism, such as objectivity, is challenged.

We are being hypocritical when we pretend instrumentalism and hide our difficulties with material realism behind this pretension. So this kind of argument need not be taken any more seriously than the argument of the olden days to accept religion as "faith." But there are others who have raised serious objections, paradoxes really, against von Neumann's proposal. Let's consider these paradoxes.

The Paradox of Dualism

The first and foremost objection against consciousness' collapsing the quantum wave function is the implicit dualism. How does anything nonmaterial interact with anything material? How can a nonmaterial consciousness collapse the wave function of a material object? Or to get back to the paradox of Schrödinger's cat, how can one little peek by a conscious observer make such a huge change in the cat's condition so that the cat changes from its "both dead and alive" state to either dead or alive?

Face it, it reminds one of Cartesian dualism. Descartes introduced the idea of a nonmaterial soul or mind, but when the princess of Bohemia asked him, "Prey tell, how does the soul affect the body?" Descartes' answer was lame, "Through the Pineal gland." But the pineal gland is part of the body also. How can a nonmaterial soul interact with something material without the intermediary of a third substance? Moreover, we know such interaction must involve the exchange of energy between the physical and the soul substances. But the energy of the physical world alone is always found to be conserved. No

physical energy ever goes to the mental world, and no mental energy ever enters the physical.

And if this paradox of apparent dualism does not thwart our enthusiasm for introducing consciousness into physics, there is also the paradox of Wigner's friend.

Wigner's Friend

Eugene Wigner, a Nobel laureate, is one of the few establishment physicists to give early support (for a time) to the idea that it may as well be consciousness that collapses the quantum wave function. But Wigner's keen intellect also discovered a paradox basic to this idea.

Here is the paradox. Go back to Schrödinger's cat. Von Neumann says that a conscious observer taking a peek at the cat's condition will collapse its wave function to dead or alive, according to the choice of the observer. Now suppose, instead of taking a peek directly, Wigner sends his friend to look, but at the last second, decides to look anyway over the shoulder of his friend. Now there are two observers to choose the cat's actual condition from the two contradictory possibilities, and suppose the choices contradict. Wigner is a cat lover, but his friend hates cats! Whose choice counts? This is the paradox of Wigner's friend.

One way to get out of the paradox is a philosophy called solipsism—the idea that only Wigner's consciousness is real and everyone else, including his friend, is just a figment of Wigner's imagination. But this is a hard position to accept, although each one of us has a tendency to feel solipsistic on occasion. The problem is that we all feel this way, and how do we figure out who is that one "head honcho," the only conscious being whose choice counts? Wigner himself talks about this:

> It follows that the being with a consciousness must have a different role in quantum mechanics that the inanimate measuring device...This argument implies that "my friend" has the same type of impressions and sensations as I—in particular, that, after interacting with the object, he is not in that state of suspended animation...It is not necessary to see a contradiction here from the point of view of orthodox quantum mechanics, and there is none if we believe that the alternative is meaningless, whether my friend's consciousness contains...the impression of having seen [either a dead cat or a live cat]. However, to deny the existence of consciousness of a friend to this extent is surely an unnatural attitude, approaching solipsism, and few people in their heart will go along with it.

But if we don't go along with solipsism, the alternative is also hazardous. Contradictory choices becoming actualized all over causing pandemonium is not a very appetizing scenario either.

When I was a post-doctoral researcher of "regular" theoretical physics, I was told to keep away from the "bottomless pit" of the quantum measurement problem and, in particular, the consciousness resolution of it, because of this paradox of Wigner's friend.

Who Is Correct—Bohr or Von Neumann?

Let's go back to the Copenhagen interpretation of quantum mechanics, and especially to the view of Niels Bohr about this question of when is a measurement? Does a measurement have to wait till a conscious observer comes along and looks, as von Neumann maintains, or is the measurement complete earlier in the chain, say with a measurement apparatus. Von Neumann has a good argument, no doubt, but it is still theory. Experimentally speaking, at least according to material realists, all an observer is is a brain. What is so special about the brain?

Let's hear out the alternative, Bohr's position, once again. Bohr agrees with von Neumann that the measurement apparatus and the quantum system do become inexorably entangled during the measurement process, so entangled that it is impossible to speak of the wave function of one without the consideration of the wave function of the other. And furthermore, these wave functions become entangled with that of our brain, without which clearly no observation is complete. So between the submicroscopic system and the brain, where can we draw a line saying that here is where the measurement takes place? Von Neumann says we cannot even draw the line at the brain; we must jump out of the system and recognize a nonmaterial consciousness where the chain terminates. Bohr says we can and we must draw the line at the measurement apparatus, which must be regarded as "classical" because of the "indispensable use of classical concepts in the interpretation of all proper measurements."

Mathematically, von Neumann's position is solid, and Bohr's position is untenable as we have already seen. But experimentally speaking, how do we discern between the two positions? How do we experimentally prove that the wave function does not collapse at the level of the measuring apparatus, that the wave function collapse requires the brain and, ultimately, the observer's consciousness? The experimental program SQUID discussed in Chapter 15 goes only partway in answering this question—no, the wave function does not collapse at the level of the measuring apparatus whose behavior remains quantum behavior.

CHAPTER 18

The Idealist Interpretation

Quantum mechanics had idealist leanings from the beginning. If quantum objects are both wave and particle, but with a given experimental arrangement, we can measure either the wave aspect or the particle aspect, then clearly *we* are choosing how the object manifests. By choosing the experimental arrangement, we are choosing whether the object will manifest as a wave or as a particle this time around. Also, since the quantum wave function represents a wave of possibility, and since when we observe we never see the electron smeared about but only as a localized actuality, the question lurks behind these realizations, Is it our observation, us, that is collapsing the quantum object's possibility wave into an actual particle?

The fact is that quantum mathematics has no recipe, no algorithm, for either of the two kinds of choices we seem to be confronted with in dealing with quantum objects. So are these choices the free choice of our consciousness, occasions of our free will?

When Niels Bohr originally discovered his model of the atom, he pondered the question of free will behind electron's quantum leap from one atomic orbit to a lower one. Who decides when and where to jump? He considered the idea that an electron itself has free will, but quickly abandoned it.

After quantum mechanics was discovered, the first big international meeting of physicists to consider the interpretational aspects of this new physics was held at Solvay, Belgium, in 1927. Both kinds of questions of choice were discussed. Bohr and Heisenberg were more interested in the choice of apparatus, what kind of questions do we put to nature? The question of choice among possibilities that leads to a unique actuality was taken up by Paul Dirac. But Dirac missed an opportunity of breaking away from realist

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prejudices by suggesting that the choice belongs to nature, as if by relegating nature with the role of choice-maker, we can make the whole situation objective and adhere to scientific realism.

Bohr and Heisenberg went ahead and developed the Copenhagen interpretation of quantum mechanics (see Chapter 8), which became the establishment opinion for many years to come. The Copenhagen interpretation was radical and went beyond strict scientific realism in several aspects. The discontinuity of the collapse of the wave function in quantum measurement was explicitly acknowledged. The wholeness (inseparability) of the measurement apparatus and the measured quantum object was also acknowledged. To the realists' dismay, it was declared that "There is no phenomenon unless it is a registered phenomenon." But again we see a missed opportunity to introduce consciousness. There is no phenomenon unless it is registered, but where? Bohr compromised to please the experimental physicists of his day. We cannot draw the line as to exactly where, but we must draw the line, said he. Let's agree that the measuring apparatus, whose behavior is classical for all practical purposes, collapses the quantum wave function and quantum possibilities become actuality. To be sure this is a classical-quantum dichotomy—the new physics for the micro objects of measurement, and the old physics for the experimental apparatuses, but it is a fact that we cannot seem to do without these measurement apparatuses. So unless and until their role is crystal clear, the ambiguity remains.

The dictum that there is no phenomenon unless it is a registered phenomenon is clearly against the realist dogma of independent, objective reality out there. But by equivocating on the issue of who or what the observer is, the Copenhagen interpretation also opened itself to a logical positivistic escape: "Whereof we cannot speak, thereof we must remain silent." To his credit, Heisenberg did say that the wave function does not represent the quantum system, but our knowledge of the quantum system. Therefore, according to Heisenberg, the discontinuous collapse of the wave function is not a physical event the way realists perceive physical events, but represents a change in our knowledge of the system. The discontinuous collapse is in our experience of the change in our knowledge. But the strong currents of logical positivism in Europe at the time prevented Heisenberg from pushing further. Physics is about our experience, no doubt, but we must not go further and examine the ontological implications of this.

It must also be noted that in the early days, quantum physics was strongly identified as the physics of the submicroscopic world. That its laws govern all material reality was an idea that lurked in the background but did not surface. John von Neumann was the first to recognize the falsity of any quantum-classical dichotomy; thus he could clearly see that a measuring apparatus itself is quantum possibility, and, therefore, could not help resolve or reduce the possibility structure to an actual event of a quantum system that it is supposed to measure. Its job was not to measure, but to amplify the signal. *We* are the observer; there is no phenomenon unless it is registered in us, in our experience.

But what is "us?" "Us" cannot be the brain, because the brain, being material, must also obey quantum laws of probability calculus. So "us" is an entity that transcends the material world, transcends the laws of quantum mechanics. This entity must also be the knower, because, as Heisenberg said, collapse of the wave function is about knowing. So it is the knower in us that collapses the quantum wave function and the infinite von Neumann chain. This knower, the knowing facility in us, is consciousness.

Now, historically speaking, von Neumann talked in terms of a psychophysical parallelism when speaking of the observer. There is the physical in the observer that can be spoken in physical terms, all the physical processes can be delineated, but at some point we must say that these physical processes are observed and known by the psyche, and there exists no description of this latter process. The observing psyche exists parallel to the physical; it is a dual body to which physical laws do not apply.

So the first objection to von Neumann is this matter–consciousness dualism. If matter and consciousness are dual bodies going on parallelly, what maintains the parallelism? How does knowledge occur exactly at the same moment that the brain is physiologically registering the position of the pointer of the measuring apparatus? Isn't the Cartesian interaction dualism lurking behind this? (See Chapter 17.)

Going back to history, it may be Fritz London and Edmond Bauer in the 1940s who first used the word consciousness explicitly in connection with quantum measurement and the collapse event. Eugene Wigner, a Nobel laureate, took up the case for consciousness as the collapsing agent in 1962.

Wigner had a love-hate relationship with the idea of consciousness' collapsing wave functions. He supported the idea for a while, then he saw a paradox, the paradox of Wigner's friend. Later, he gave up the idea.

Dualism and the paradox of Wigner's friend practically killed von Neumann's wonderful idea, and many physicists moved toward an instrumentalist view of the problem of interpretation of quantum mechanics. Perhaps physics does not have anything to say about reality and its metaphysics. Perhaps physics is an instrument to analyze experiments and make predictions, and only that. Long ago, in a letter to Galileo, the Pope asserted a similar instrumentalism for the role of physics vis-à-vis reality. Neo-Copenhagenists of the '80s unabashedly revived instrumentalism as an escape from the "endless gutter" of the quantum measurement problem. "Let's not ask certain questions," became accepted wisdom.

But in the '80s there were also new currents toward a consciousness-based resolution of the quantum measurement paradox. In the '70s, physicist Fritjoff Capra wrote his book *The Tao of Physics*, pointing out parallels between Eastern mystical thought and certain trends in physics. Even earlier, physicist Fred Alan Wolf wrote a delightful, popular exposition of quantum mechanics where he freely used von Neumann's idea that consciousness collapses quantum wave functions (and coined the new-age, very confusing phrase, "We create our own reality"). In the beginning of the '80s, Aspect's successful experiment put the nail in the coffin of material realism for anyone who was philosophically astute. At about the same time, physicist Henry Stapp began to use Alfred North Whitehead's philosophy to interpret quantum mechanics with clear idealist leanings.

Monistic Idealism

Idealism gets a bad rap in the West because of many historical misunderstandings. If we look at our experience, clearly there are distinct outer and inner components to our experience. The realists emphasize that the outer, objective, material reality is everything, and the inner reality, mind, is an epiphenomenon of matter. So idealism is regarded as the

mirror opposite of the material view: the internal world, mind, is primary. Matter is but akin to dreams of the mind. It makes sense at first glance. After all, we are in direct touch with our internal states. And it makes sense to say that all our information of the outside comes from our sensory impressions, which are experienced inside. So the inside world, mind, must be primary.

But on closer scrutiny, this kind of idealism falls short of a true monism. Truth is, both mind and matter, internal and external, are experienced by consciousness, the experiencer that must transcend both matter and mind. The difficulty of the above kind of dualism is arising from the inability to distinguish mind (the world manifest in interiority) from consciousness, the experiencer, which is never manifest, which is not an object. Instead, consciousness must transcend both mind and matter.

A philosophy called neutral monism does better. Here one tries to bring symmetry in the situation of whether matter or mind is primary by positing a deeper holistic substance of which both matter and mind are two aspects, like the two sides of the same coin. But this still misses the transcendent aspect of consciousness.

Other Western philosophers, notably Immanuel Kant, have tried to include transcendence, but have declared the transcendent as unknowable. This, too, falls short because it does not recognize the unity of individual consciousness with the transcendent unity.

In monistic idealism, which is also called perennial philosophy and is the esoteric basis of all of the world's great spiritual traditions (and as that basis it is often called mysticism), consciousness is the primary being of the world and is transcendent. All immanent beings of the world, matter and psyche, which includes mind, are aspects of consciousness, but consciousness is also outside these immanent objects. This "it is within all this, it is outside all this," is the meaning of transcendent consciousness.

So in monistic idealism, there is only consciousness, the one without a second, and yet it does become many. How does the one unity become separate, become individualized to create the appearance of independent, separate objects of realism, as well as all the individual egos, the minds, that experience them? In monistic idealism, this is left as an unexplainable mystery (it is called *maya* in the Indian Vedanta philosophy). The mystery lasts as long as we are oblivious of the true nature of reality due to ignorance. When we penetrate the ignorance, the light of knowledge as to the true nature of consciousness shines. We can penetrate the ignorance and become "enlightened" because "we are that." Mystics of both East and West are more interested in epistemological penetration of the ignorance, rather than metaphysical discussion of cosmology—how the apparent world of scientific realism originated. This is because mystics know that in penetrating the ignorance is where happiness that everyone seeks can be found.

But this ignoring of the manifest world is often misconstrued as a denigration. And this is not entirely a misconstruction. In some traditions, maybe even in all traditions, there is an element of denigration. In particular, in Christianity the denigration is prominent and is carried out within a dualist misinterpretation of the mystical message of Christ. So modern science, which originated in a Christian culture, has locked horns with religion from its very beginning. This antagonism has led to a rift between science and anything mystical.

But the truth is, quantum mechanics is mystical, if by mystical we mean that there is, in quantum mechanics, a fundamental mystery, the discontinuous collapse, for which

also, like the mystic's *maya*, no algorithm, no mechanism, can be given. Suppose we suspend our prejudice and ask, If quantum collapse is due to consciousness, what is the nature of this consciousness? You will be surprised with what we find.

Quantum Measurement and the Nature of Consciousness

Let's take up the paradox of Wigner's friend first, because this was the first paradox to be solved—although this solution by the Australian physicist Ludwig Bass was published in such an obscure journal that it went almost completely unnoticed. Years later, I independently discovered the same solution, and still later Casey Blood of Rutgers University in New Jersey also discovered it independently.

What did all of us discover at three different corners of the world and at three different times but without knowing about the others' works? Simply this. Examine why the paradox of Wigner's friend is arising. Two people, you and your friend, let's say, are simultaneously looking at a street traffic light, but from perpendicular directions (Figure 18.1). The traffic light is "quantum" in the sense that the light changes to green only when a radioactive atom (of appropriate half-life) decays. But who gets to choose green, you or your friend? Being busy people, it makes sense that both of you will want green, but there is a contradiction here: if your friend gets green, you don't, and vice versa. So again, whose choice counts?

Why is the paradox arising? It is because you think, as does your friend (and practically all of us), that we have individual consciousness, each of us has a choosing consciousness. Suppose instead, the choosing consciousness is one (Figure 18.2), we all share it, although admittedly this oneness of all of us is somewhat obscured from our everyday experience. So, the answer to whose choice counts is neither and both. Neither at the level where we ignorantly think that we are individual consciousness; both at the level where we are one and are beyond the realm of personal conflicting desires. And how does

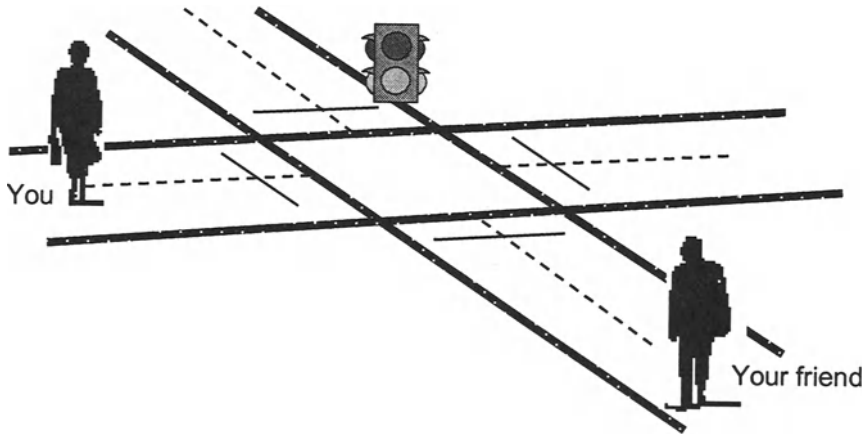

Figure 18.1
Who chooses whether the light is green or red?

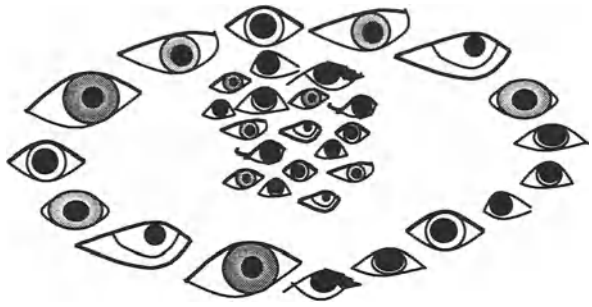

Figure 18.2
The diverse "I"s of sentient beings ultimately are the one "I" of consciousness (pun intended).

this one consciousness choose? Does it play favorites? We cannot say. The one consciousness makes its choice out of its free will. Its free will is free only because we cannot say anything explanatory about it. All we can say is that for a large number of collapses of the traffic light, it will collapse an equal number of times in red and green.

At first glance, this seems to be a very mystical position—the unity of consciousness. Etymologically, as Erwin Schrödinger knew, consciousness is a singular for which there is no plural. Actually, we know it, too, intuitively.

Dualism

How is the paradox of dualism to be solved? Again, the solution is very simple, but it requires a complete about-face of our worldview. How can consciousness collapse the quantum waves of possibility without dualism, without expending energy? Because the possibilities are already within consciousness. Consciousness, not matter, is the ground of all being, and material objects are possibilities for consciousness to choose from. When consciousness chooses, via discontinuous collapse, a measurement or observation is made.

How does consciousness choose? What is involved? To see this clearly, examine the gestalt picture in Figure 7.14. What do you see? Perhaps a young woman or perhaps an old woman. The artist, W. E. Hill, named this picture "My Wife and My Mother-in-Law." But are you doing anything to the picture in what you are seeing? No. You are recognizing one way of seeing the lines, and that's your choice in this view. Another time, you look at the lines differently, and another recognition, another choice.

So quantum collapse is like this. We choose by recognizing one of the possibilities that are already within us. These possibilities evolve via quantum dynamics and upward causation, and present us with possible events to choose from. At every instance of experience, we recognize one of the possibilities, we choose, and experience what we choose. This is *downward causation*.

The Apparent Subject-Object Duality

But there is a subject-object duality in our experience; how is this created? The answer is subtle. The artificial intelligence researcher Doug Hofstadter has shown how self-refer-

ence, this separation of a self from the rest of its environment, arises. Consider the sentence, "I am a liar." In an ordinary sentence the predicate qualifies the subject and that's that. You are a reader. The word reader qualifies you, and that's that. But not so for the sentence "I am a liar." The word "liar" qualifies "I" to be sure, but if I am a liar, then I am telling the truth, and then I am lying, and so forth. So, "I" qualifies "liar" back. And this mutual qualification oscillates. If I am telling the truth, then I am lying. Contradiction again and again. This goes on *ad infinitum.* Once you get into this infinite oscillation, you cannot get out. Now you see how self-reference arises. "I am a liar" is a self-referential sentence because it, by virtue of its infinite oscillations of its levels of hierarchy, has become isolated from the rest of the world of discourse.

Hofstadter calls such infinite oscillations of hierarchies "tangled hierarchies"—the causal levels of such a hierarchy seem to be forever tangled. The other thing to notice is that in truth, neither of the levels of the hierarchy has any real causal efficacy that lies outside. In "I am a liar," why is the tangle arising? Because we are going along with subtle rules of English grammar and recognizing the tangle. In effect, we are the one with causal efficacy. Consciousness is.

A Sufi story gives you the flavor of a tangled hierarchy. Mulla Nasruddin, a Sufi teacher of crazy wisdom, one night saw some horsemen coming toward him and became afraid and started running. But the horsemen were coming toward him because of him—they wondered if they could be of some help. However, when they saw Nasruddin running, they became suspicious and kept following him. Then Nasruddin became really afraid and started running even harder. You see how it goes. Eventually, Nasruddin came to a cemetery and tried to fool the pursuers by hiding inside an empty coffin. But the horsemen found him. As they opened the cover of the coffin and asked Nasruddin why he was in a coffin, the Mulla said, "I am here because of you, and I now can see that you are here because of me." The synchronicity of their conscious thinking got them there!

Similarly, the infinity of von Neumann's chain is a tangled hierarchy. Neither the quantum system nor its infinite chain of measurement apparatuses has the causal efficacy to collapse the possibility waves they are. Only consciousness does. Our brains simulate similar, tangled hierarchies by creating infinite oscillation. In the brain the quantum system that responds to stimuli and the measurement apparatus that amplifies are of the same size (as pointed out by Henry Stapp), so their hierarchical relationship is blurred. In effect, they keep feedbacking and amplifying each other's outputs, creating a tangled hierarchy, and ultimately they cannot resolve this tangle.

When consciousness collapses the possibility waves of the brain's tangled hierarchical system, thus entering it (so to speak), it cannot get out, it identifies with it and construes itself as the (separate) subject from the external objects of the collapsed experience. And this one consciousness, undivided from its material possibilities, become divided into a subject that sees and experiences what it sees, and object(s) that are seen and experienced (Figure 18.3). But this is only appearance. And neither the subject nor the object creates the other. It is dependent co-arising, to use a Buddhist description.

For a novel stimulus, the experiencing subject has no past memory or history, and thus, the subject-experience is universal and unitive (recall the oneness of a creative experience of your childhood!). I call this universal self the *quantum self.*

We create our own reality, just as in the popular new-age slogan, but there is subtlety.

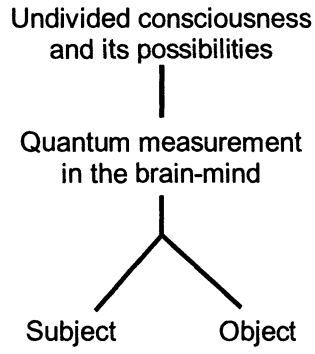

Figure 18.3
The result of tangled-hierarchical measurement is self-reference.

We create in a nonordinary state of consciousness in which we are one; and we are co-creators of the world along with the objects of our creation.

But we forget both these aspects of the quantum self. With experience, memories are added in the brain. This is another job of the measuring apparatuses (we should really call them measuring aid apparatuses)—they make a record of the result of the collapse. So for a previously experienced stimulus, the consciousness responds, not freely, but only upon reflection from the mirror of past accumulated memory. The reflection in the mirror of memory produces a modification of probabilities of responses in favor of the previous response. And further reinforcement produces further conditioning. Eventually, we end up having a pattern of response that we call our character. When we identify with this pattern, we see ourselves as having causal efficacy, as being the head honcho of our brain's learned programs. This and our remembered history give us our individuality. This is our ego.

And thus, the one consciousness becomes many in two stages. In the first stage, a subject-object split is created, and objects are seen as independent and separate. In the second stage, experiences come to us after many reflections in the mirror of memory (Figure 18.4) producing conditioned and individualized patterns of responses, creating a multiplicity of subjects.

So, is consciousness necessary to understand quantum mechanics? Yes, it is, but it takes a while to get it, to really understand and appreciate the implication of this. In the next chapter, I have created a summary tour for you through the important steps of this understanding.

The Epistemological Question

The metaphysics of monistic idealism solves the quantum measurement problem, but now we are faced with the epistemological question: How do we know consciousness, this ground of being that we are ontologically positing?

There are really not one, but three ontological positions regarding consciousness that we are positing that call for suitable epistemology:

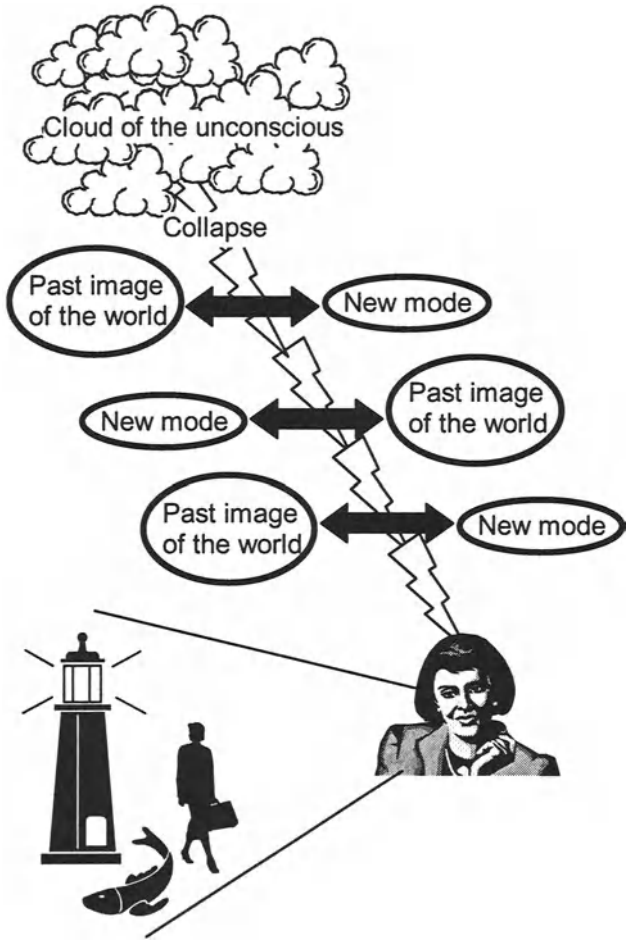

Figure 18.4
How the ego develops via the reflection in the mirror of memory.

1) the nonordinary state of consciousness in which quantum collapse occurs is one and universal without any individuality;

2) there is consciousness beyond the subject-object split, which is the result of collapse; and

3) consciousness is the ground of all being; ultimately there is only consciousness, one without a second.

These ontological positions are impossible to verify via reasoning or any continuous means because quantum collapse itself is discontinuous. This makes the epistemological question somewhat mysterious. Fortunately, spiritual traditions, especially the Eastern traditions, have developed elaborate epistemological techniques, commonly referred to as meditation, but there is quite a bit of variety there that when followed lead to these ontological positions quite unambiguously. Going into a discussion of these techniques is too far beyond the scope of this book (for a small taste, see Chapter 23), but the great masters of all the great traditions have borne witness to the epistemological validity of

these techniques throughout history. For example, in the Hindu tradition, the experience of oneness is referred to as *swavikalpa samadhi* in the literature. Consciousness beyond subject-object split (but not sleep, in which there is no cognition and no wisdom) is called *Nirvikalpa samadhi*, and the wisdom of consciousness as the ground of being is referred to as *Turiya*.

Bibliography

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Putnam/Tarcher, 1993.

Goswami, A. *The Visionary Window: A Quantum Physicists' Guide to Enlightenment*. Wheaton, IL: Theosophical Publishing House, 2000.

CHAPTER 19

A Summary Tour of Quantumland

The tour guide sees you hesitating. "It's really a great opportunity," he reassures you.

"I don't know. I've always been afraid of quantum mechanics, I guess. I've heard people say, physicists included, 'nobody understands quantum mechanics.'"

"That's because they try to understand it with faulty philosophy—that only matter is real. If we agree that only consciousness is real, and matter represents possibilities within consciousness, a quantum mechanical description of matter makes perfect sense. You will see."

"All right." You reluctantly go along. It better be good, you say to yourself.

The tour guide takes you to a man—forty-ish and handsome—looking at what seems to be a mathematical equation on a blackboard:

$$i = \sqrt{-1}$$

You wonder, Is there any such thing as the square root of -1? "Why don't you ask Professor Schrödinger?" the tour guide says, as if reading your mind.

Professor Schrödinger is amicable to your question. "There is the mystery of quantum mechanics right there," he says with an adorable accent. "You see, mathematicians call the

A. Goswami, *The Physicists' View of Nature*
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square root of negative 1 i, which stands for imaginary. They agree that such numbers do not ever represent anything in the real world, but they find it useful to play various games of mathematical fancy. Now here is what is strange and wonderful both at once. When I discovered the equation of matter waves, I found that the equation contains i in such a way that the waves are 'complex.' That means that they are represented in part by real numbers and in part by imaginary numbers."

"Slow down, Professor," you manage to interject. "What do you mean 'matter waves?' Matter doesn't seem very wave-like to me."

"That's because you are thinking of bulk matter—baseballs and such. In the submicroscopic realm, when you deal with electrons—those tiny bits of electricity that dance on your TV screen invisible to you—you find that matter is demonstrably wave-like."

"You mean they spread out like the waves on water?" Your interest is piqued.

"That's exactly what I mean. For bulk matter, the spreading is too slow for us to measure it. But when experimenters send electrons through crystals, they can measure this spreading quite well," Schrödinger says. "However, even I was not ready for the wave functions'—the mathematical functions representing the waves'—having complex in their nature."

"Why didn't you send them to a psychiatrist, those Freudian analysts?" You can't resist. "They can treat any complex."

"You are joking," says Schrödinger smugly. "Only physicists can solve physics problems. The solution was given by my friend Born. He said, to cure the complex, take the absolute square of the wave function—a mathematical procedure of multiplying a complex number by its conjugate—which gives you a real number. He said that the square of the wave function at a point of space represents the probability that the object should appear there in case we try to find it. When we plot it looks like those bell curves you surely have seen."

How strange, you think. The waves are not real, but if you make them absolutely square, they give real probability. What are the waves then? Possibilities? Possibilities to appear in all those places for which the probability is nonzero?

"I guess you can call them that—possibility waves," answers Schrödinger to your question. "Look, I've got to help somebody else." He leaves you in a hurry and moves toward a pretty woman who just entered your field of view.

Your tour guide smiles. "Don't take it personally. Given a choice, Professor Schrödinger prefers the company of women, especially pretty ones."

But you are not offended, you are lost in thought. "If matter is only possibility, where does it reside? Nobody has seen possible matter in the real world. So how does it become an actual, real-world thing?" you ask the tour guide.

"Oh, yes. Our looking collapses the possibility waves into actuality. So where do they reside when we are not looking? Let's go ask Professor Heisenberg, the co-discoverer of quantum mechanics."

Uncertainty and Potentia

Heisenberg, although young and brash, is very helpful. "I took a very different track

to quantum mechanics," he says. "I thought that the variables that represent an electron's movement, let's say its momentum (mass times velocity) and position, are noncommuting quantities. You know about law of commutativity of algebraic quantities, don't you?"

"You mean the idea that *a* times *b* is the same as *b* times *a*? That the order of multiplication does not matter?"

"Exactly. I postulated that momentum and position do not commute. And that gave me the equation of quantum mechanics, the same equation as Schrödinger's, by the way, but in different garb. But what does it mean, that the order in which we multiply matters, from a measurement point of view? Simply this. Measurement of one variable affects the knowledge of the other variable. In other words, we can never simultaneously measure both variables, both momentum and position, with utmost accuracy. I call this the *uncertainty principle*. So why is quantum mechanics probabilistic? Because the uncertainty principle is intrinsic to their being. Why are quantum waves mere possibilities before we observe them? Because it is impossible to assign them both position and momentum simultaneously, properties that we need if we are to see them as Newtonian objects."

But you are full of questions. "But we do see them, don't we? How does our observation give them simultaneous values of momentum and position?"

"Well, we do see them, but only with the intermediary of macro-objects, measurement apparatuses such as a Geiger counter. The measurement apparatuses amplify the electron's signals; they also provide the much-needed grounding in reality."

You are bubbling with excitement. "One final question. Where do the possibility waves of submicroscopic matter reside before we see them with our measurement apparatuses?"

"Well, many people find that a little mysterious. I say that they reside in transcendent potentia. After all, whenever we measure a quantum object, however spread it is as a wave of possibility, it seems to collapse instantly without wasting time; if it were a space-time entity, Einstein's relativity would demand that it collapses at light speed, at most. So there is reality beyond the material world, beyond space-time. This is similar to Plato's thought that the material objects of this world have their origin in 'archetypes' of a transcendent world. The objects we see are a mere shadow show, mere projections of the transcendent waves of possibility cast by our measurement. Any problems with that?"

No, no problems at all. Everything is cool.

Consciousness and the Quantum

"Professor Heisenberg never mentioned consciousness. You said we need consciousness to understand quantum mechanics," you complain to your tour guide.

He throws you a sweet smile. "You let him off easy. Why didn't you ask him if it is completely accurate to say that measurement apparatuses are actual Newtonian objects (with both position and momentum), since they themselves are supposed to be made of these potential, submicroscopic objects?"

You think it over. It is true, everybody knows that all macro-things are made of the submicroscopic things, electrons, quarks, and such. So Heisenberg did not tell the whole story.

"What's the solution to the puzzle of collapsing possibility into actuality if measurement apparatuses are unable to perform that task? Yes, I agree with you, logic is on your side. Things that are made of possibility waves must themselves be possibility waves, though being sluggish to spread, they may be arbitrarily close to actuality. So even after an electron falls upon a Geiger counter, the signal, albeit amplified, remains in possibility, no projection to reality yet. What causes the projection, the shadow show?"

"What does Plato say?"

"You mean the allegory of Plato's cave. Well, Plato said that it is light from behind the archetypes that casts their shadows on the cave wall (Figure 19.1)."

"Light is a metaphor for consciousness. Quantum mechanics needs Plato to make sense of it. When consciousness looks, then only the quantum possibility wave collapses into actuality. Before collapse, possibilities are possibilities in consciousness for consciousness to choose from."

But somewhere he loses you. Questions swarm in your head. What is consciousness? If he means me, why don't I feel like the chooser when I hear the Geiger counter go ticking in the presence of radioactive material? He senses your confusion, too. "Let's take you to see Professor Bohr, Niels Bohr, the second greatest scientist of the 20th century, after Einstein. He will help you comprehend."

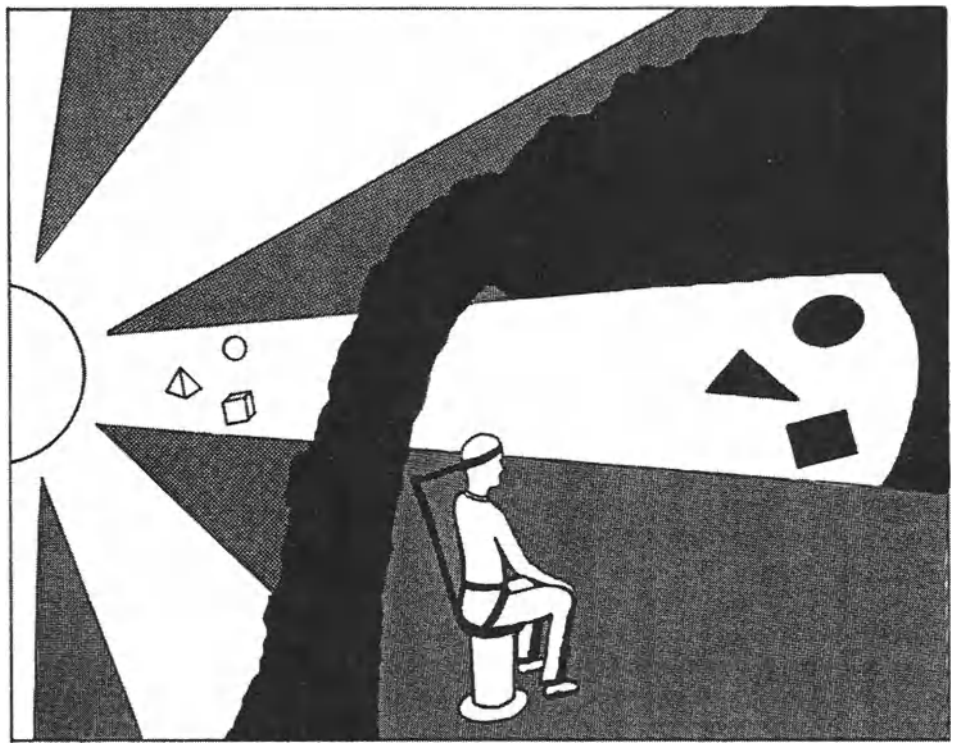

Figure 19.1
Plato's allegory of the cave.

The Double-Slit Experiment

You find Professor Bohr standing in front of a blackboard with his cigar, oblivious to the fact that it has gone out. On the board is a drawing (see Figure 7.1). In answer to your question, Bohr explains.

"This is the arrangement of the double-slit experiment. An electron gun aims a beam of electrons at a two-slitted screen. After the electrons pass through the slits they are detected on a fluorescent screen beyond. What do you think you would see on the fluorescent screen?" Bohr asks quizzically.

"That's easy. Right behind the two holes, there would be two bright fringes. Because only those electrons that make it through one or the other of the slits would make it to the fluorescent screen," you say without hesitation.

"Wrong. You are thinking of electrons as baseballs, not an uncommon mistake," Professor Bohr says in a mischievous tone. "You forgot that electrons are waves. Waves spread. So each of the electrons will spread and pass through both slits, become two waves. The two waves of each electron will interfere (Figure 7.2). If the two waves arrive at a point of the screen in phase (obviously, that depends on the distance traveled by each wave), they interfere constructively, and you get a blip. Those are the places where you get a light fringe, many more than two. In between, you get dark fringes; the two waves arrive at those places out of phase and cancel each other out. So there is a pattern of dark and bright fringes called the interference pattern."

"Fascinating!" You are out of breath in amazement.

"Some people call it quantum magic," Professor Bohr smiles.

"Wait a minute," you blurt out as you regain your composure and realize that there is a less than magical explanation. "What makes you think that the electrons are interfering with themselves. Wouldn't you get the same pattern if the waves of two different electrons interfered? That way you save me from the magical idea that an electron can split. After all, it is a material object, it's got to have some integrity."

But Bohr shakes his head. "If we make the beam very weak, so weak that only one electron is passing the two-slitted screen at any given time, even then we get the interference pattern of many alternate bright and dark fringes, although it takes a little longer exposure to see the pattern clearly. So each electron must be interfering with itself. Quantum magic prevails."

"If you say so. I still am having a hard time believing that an electron, an object with mass and charge, real tangible stuff, can split in two—"

"—And rejoin," Bohr interjects. "When we see the electrons, we see one blip on the fluorescent screen for each electron, very localized, not smeared out."

"Now I am totally confused. If electrons are waves, how come when we see them, we see them as localized particles?"

"Electrons are both wave and particle. They are waves when we don't see them. They are particles when we see them. But it is also true that electrons are neither wave nor particle. They behave like waves when we don't see them, but appear localized, not smeared all over, when we do see them. But even so, they appear at places on the fluorescent screen forbidden to baseballs, where only waves can go."

"Now you are shocking me. How can the same object be both wave and particle and neither wave nor particle in the same breath?"

"Those who are not shocked when they first come across quantum mechanics cannot possibly have understood it," Bohr says, gravely lighting his cigar.

Oh great! Now you not only have to deal with quantum shock, but also cigar smoke.

"Look, it's not so bad," Bohr says kindly. "The wave and particle properties are complementary aspects of the same thing. The wave aspect is transcendent, the particle aspect is immanent. Like the immanent *yin* and the transcendent *yang* in the figure-ground relationship of the Taoist symbol (Figure 19.2)." Bohr's face becomes soft as he reminisces. "Ever since I discovered this complementarity principle, I've been fascinated with it. I wore the Taoist symbol on my coat of arms, you know, when I was knighted by the king of Denmark."

That analogy mollifies you some. "Thank you, Professor. It's making a little bit of sense now. But I am still not convinced that an electron ever goes through two slits simultaneously. Maybe it goes through one slit, but travels a weird trajectory to reach those places on the fluorescent screen unreachable to baseballs. Why don't we settle the question by looking?"

Professor Bohr seems infinitely patient with you. "Why don't we do an experiment, eh? Look to see if an electron is passing through one slit only and not the other. Okay, get a flashlight and aim it at the slits. What do you think happens to the interference pattern?"

"Should anything happen?"

"Yes, our seeing affects the electrons. Their waves collapse at one slit or the other, they no longer pass through both slits—no split, no interference, no interference pattern."

You are a little stunned. So there is no way to check out if the electron is really passing through one slit and making a weird trajectory without destroying the interference pattern! Too bad. Then you think of your quintessential question once again.

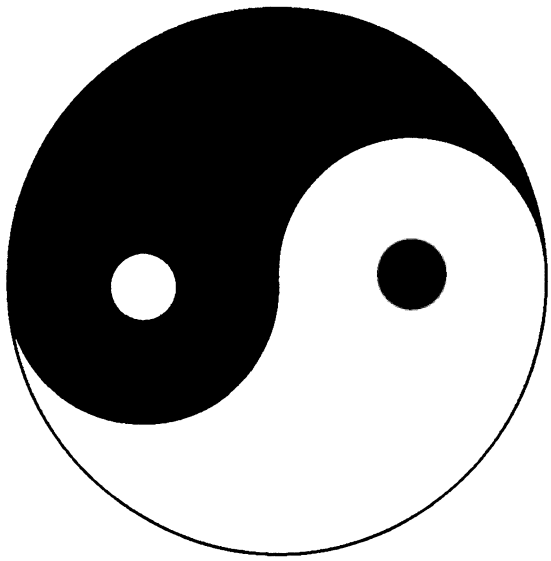

Figure 19.2
The *Yin-Yang* symbol.

"My tour guide says that we cannot understand quantum mechanics without injecting consciousness in our discussion. Can you explain that one to me?"

Bohr is very patient. "The wave and particle aspects of the electron are complementary in another way also. You can see only one aspect with a given experimental arrangement. The double-slit arrangement (Figure 7.1) is an arrangement fitted to see the wave aspect. The arrangement with a flashlight aimed at the slits (Figure 7.4) is a particle aspect measuring arrangement. Here is the thing. We choose what aspect the electron will take on by choosing the experimental arrangement to see it with. So your tour guide is right. Subjects and objects do get mixed up in quantum measurements. Can't say I like it. Science should be objective." His cigar has gone out again, you notice.

Back in private with your tour guide, you express your gratitude. "That was very educational. I thought I understood possibility waves and their collapse from Heisenberg, but I didn't. I only hope I do now."

"Want to bet on it?"

"No bets. But you got yourself an enthusiastic quantum aficionado."

"That's all I want. That's my only reward that counts," your tour guide says solemnly. "You are ready for the ultimate confusion, Schrödinger's cat, and the ultimate light, what kind of consciousness is needed to understand quantum mechanics."

Schrödinger's Cat

The tour guide warns you. "It is a fact that we never get to see in our manifest reality what it is like in the possibility domain of the quantum reality. In this pavilion, you are going to see some strange simulations. Are you ready?"

As you nod, a box appears before you. Inside you recognize a Geiger counter, but it's not like any you have seen before. Its pointer is simultaneously pointing to two readings: "Atom Has Decayed" and "Atom Has Not Decayed." The Geiger counter is connected to a hammer, which is poised to strike a poison bottle—but lo! Superposed on this there is a hammer that has broken the bottle. On the floor of the cage stands a live cat superposed on a cat that appears to be dead.

"I have heard of this before: Schrödinger's cat is both alive and dead. How does it happen?" You volunteer.

"Quantum processes are taking place around us all the time, but usually they don't invade our macro-reality. The reason is a process called decoherence. Go back to the double-slit experiment. The reason that the possibility waves from the two slits interfere is that they have a phase relationship, they dance to the same music. For this reason, the quantum possibility wave—technically the wave function—is often called a coherent superposition. But interaction with other things can occur even in possibility. If such interactions occur, the system now include all the interacting partners, and the original phase relationship is no longer there. This is decoherence.

"So normally we don't see quantum effects on the macro-scale because the environment decoheres any quantum coherent superposition of a system. But suppose we somehow keep the system isolated. What then?

"There is a radioactive atom that you don't see with a half-life of one hour in that cage. Radioactivity is probabilistic; the probability is fifty-fifty that the atom will decay or not decay within the hour. In this way, quantum mechanics says that at the top of the hour the atom is a coherent superposition of an atom that has decayed and one that has not decayed. If the atom decays, the Geiger counter ticks, which activates the hammer that breaks the poison bottle that kills the cat. If the atom does not decay, none of these things happen and the cat lives. The atom's dichotomy propagates, producing the dichotomy of the cat."

"How interesting," you manage to say. "But even for this environmentally isolated cat, when we look at it, we only see a live cat or a dead cat—or am I wrong?"

"You are absolutely right. This is why the idealist interpretation: our looking collapses the possibility dichotomy of the cat (and all the other dichotomies coupled with it at the same time) into unique actuality. And by examining the subtleties of our looking, we now can learn a lot of what the nature of consciousness must be."

"I am trying to imagine myself as the person who opened the door of the cage and looked. You are saying that my little peek brought down all those dichotomies. I have that kind of power? Isn't that mind over matter?"

"Hardly. That old argument against dualism does not hold for quantum measurement if you think of objects as possibilities in your consciousness. When you look you recognize and choose one of the two possibilities inside you—and that's the one that manifests. This does not involve any transfer of energy or mind-over-matter."

"I get it. It's like looking at a gestalt picture, 'The Vase and the Faces' (Figure 19.3). I can recognize and choose either the vase or the faces," your eyes sparkle.

"Exactly," says the guide. "But there is a subtlety here. See those gentlemen over there? They both want to look at the cat's condition simultaneously. But they can't decide whose choice counts."

You see them all right—you can even hear them. They are arguing loudly. One man says, "It is obvious that my choice is the one that counts; I conceived this experiment. For all I know, you are nothing but a figment of my imagination."

"But Professor Wigner," says the other one, "I think you are the figment of my imagination, and it is my choice that counts."

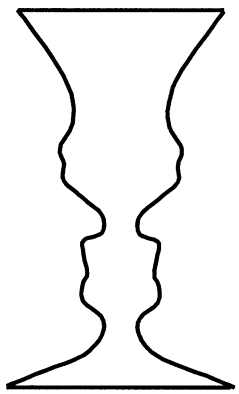

Figure 19.3
You can see a vase or two faces, depending on your perspective of looking. Similarly, consciousness chooses out of all the available possibilities by recognizing a particular perspective, and that determines the choice.

"Fascinating," you exclaim. "It's legit, too. We all see each other through sense perceptions in our head. How do I know that my senses are not playing tricks on me, giving me the appearance of other people? But anybody can say the same thing. How do we get out of this logjam?"

"By recognizing that consciousness is not a simple dualism of separate consciousness and brain. All consciousness is one. Wigner and his friend do not have separate consciousness in the state of consciousness in which the choice happens. Since it is the same consciousness that chooses in any event of quantum measurement, the paradox that Wigner and his friend are arguing about is simply a misunderstanding of the nature of consciousness. This, incidentally, is also the resolution of your question. We know that other people are conscious like ourselves because from the state that we are one we can feel the truth of it."

"That makes sense. I have another question for you. Suppose instead of directly looking at the cat I use an automatic camera. Everybody knows a camera doesn't lie. So will not the camera give away the cage's secret to me or anybody else, and we don't have to involve consciousness at all?"

"Clever. But think. The camera must obey quantum possibility dynamics as well. So it must in possibility photograph both dead cat and live cat."

"But this could go on forever! What makes you think that our brains are any different? Doesn't the brain itself follow quantum mechanics, and hence become a coherent superposition when seeing the cat?"

"That's right," says your guide. "Looked upon as a material algorithmic (quantum mechanical development of wave functions in time is also an algorithm) machine, the brain indeed itself does become a dichotomic Schrödinger's cat. At some point there must be something nonalgorithmic taking place; then the wave function can collapse.

"It has been postulated that gravity is nonalgorithmic at the quantum level, and hence gravity is involved in the collapse of the quantum wave function. But quantum collapse is not only nonalgorithmic, it is also nonlocal and discontinuous. Another possibility, of course, is consciousness, which is also nonalgorithmic (can one write down algorithms for understanding or love that are routine functions of consciousness?). Consciousness must be nonlocal; it acts from outside of space and time, but its effect is found inside space and time, hence the appearance of discontinuity."

Your rational antennae are instantly up. "But if consciousness looks from outside space and time, it can look everywhere, every time. Why doesn't it?"

Your guide looks at you with admiration. "A long time ago there was an idealist philosopher named George Berkeley who used to make materialists nuts by positing that everything is a product of the mind, because all we can know is through our mind. Then somebody asked Berkeley, 'George, suppose there is a tree falling in the forest, but nobody is there to hear the sound. Is there a sound or not?' Berkeley was in a predicament and said, 'Well, there is always God's mind.' This was an error. In the philosophy of monistic idealism—Plato's is an example—God (consciousness, that is) is not always looking. Quantum mechanics must adapt to the monistic idealist picture of consciousness if consciousness can help resolve its measurement paradox."

"That's all very interesting," you say impatiently. "But when does consciousness look and when does quantum measurement take place?"

"The idealist philosophers of the ancient times emphasized three aspects of consciousness: 1) consciousness is unitive; 2) consciousness is transcendent (which is the same as nonlocal); and 3) consciousness is self-referent in us. We have already seen the necessity of the first two aspects of consciousness in quantum measurement. Now you can see the importance of the third.

"Behold. Consciousness collapses the wave function only in the presence of brain-mind awareness."

"Wait a minute," your logic raises its head again. "Awareness is the field in which objects occur. So awareness itself is an object in consciousness, and as such must only exist as possibility before the collapse of the wave function in the brain. It is something that happens after the collapse."

"We do have a problem, don't we?" says your guide with a smile. "We cannot have collapse without awareness; we cannot have awareness without collapse, without conscious choice. What comes first, awareness or choice? The chicken or the egg?

"The answer is, neither. Quantum collapse is tangled hierarchical. You cannot tell whether the subject that chooses or the object that is chosen is the cause of the other. Their causal hierarchy is tangled. We must say, subjects and objects arise codependently from the event of collapse. Collapse is self-referential."

"You are going too fast," you complain. "Okay, tangled hierarchy of choice and awareness I understand. Where is the self-reference coming from?"

"Where there is a tangled hierarchy, there is self-reference," says your guide. "To see this, examine the self-referential drawing 'Drawing Hands' by the Dutch artist M.C. Escher (Figure 19.4). See how the left hand draws the right hand, but the right hand is also drawing the left hand. The definition and redefinitions by each hand of the other goes on indefinitely. If we identify with this infinite loop, in effect, we cut ourselves off from

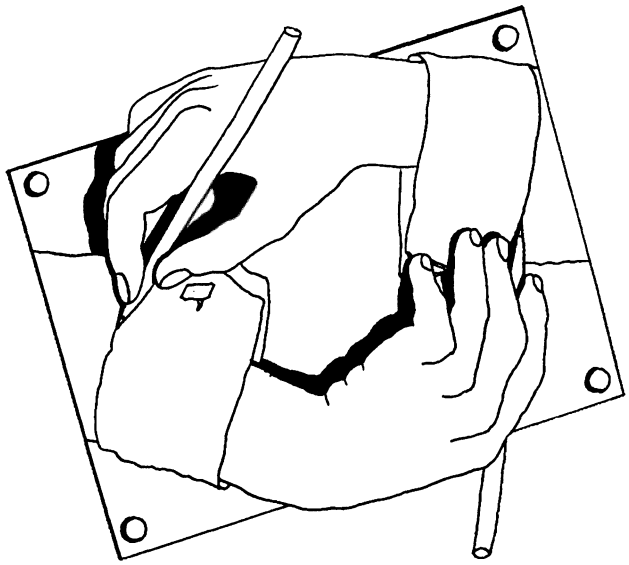

Figure 19.4
Artists' rendition of "Drawing Hands," by M.C. Escher.

everything else. Now we have a self as opposed to our environment."

You mull it over. "Yes, yes, I see it now. This is very exciting. So you are saying that it is the tangled hierarchical quantum measurement that divides the world of one undivided consciousness and its possibilities into a subject that sees and an object that is seen. But tell me, why can't the same trick be used in a materialist metaphysics to achieve the same outcome? Now that would really be exciting, because materialists worry about that problem a lot."

"That's where the idea first originated. But it doesn't work there for two reasons. First, the subject-object division that arises co-dependently is an appearance. Underneath, consciousness from a transcendent level is doing it all (as in the self-referential 'Drawing Hands,' neither the right nor the left hand is really drawing the other—from behind the scene, Escher is drawing them both, and ultimately he is drawing them from the transcendent level of consciousness). But material realism posits only one level of existence.

"Second, even if our subject-hood arose this way from matter alone, there would be no causal efficacy in that subject. In material realism all causal efficacy is upward causation coming from the elementary particles. In monistic idealism, quantum mathematics is given causal efficacy from the beginning—nobody denies the lawfulness of matter. But consciousness retains the power of choosing, so there is also downward causation relegated to the subject (but it is really the downward causation of transcendent consciousness beyond the subject-object split). Thus subjects and objects are truly on the same footing."

"I like that," you admit. "I think it agrees more with how we relate to the world. It gives us free will. However, I am still uneasy about one thing. Where does this put the question of animal consciousness? Why can't the cat collapse its own wave function? And if a cat can, can an amoebae? Are these questions stupid?"

"They are very good questions," your guide reassures you. "In truth, there is no reason to assume that the collapse of the quantum wave function requires a brain. What it does require is a vehicle where there is a tangled hierarchy in how it interacts with stimuli.

"The mathematician John von Neumann showed that we can try to measure Schrödinger's cat with an infinite number of measurement apparatuses, but to no avail; all remain in possibility. This infinity is an indication that there is a tangled hierarchy in this kind of chain. But how does a finite vehicle accommodate an infinite number of measuring apparatuses?

"The measurement apparatuses amplify the quantum possibilities for consciousness to see. Suppose at the base level, the distinction of the quantum system and its measurement apparatus is blurred; you cannot tell which is which. In effect, then, such a system is equivalent to von Neumann's infinite chain.

"This certainly happens in the brain, but we don't have to stop there. It can also happen in the living cell."

"Thank you," you exclaim with profound admiration. "I am glad I used this opportunity. Not only do I now understand quantum mechanics, but also consciousness and life."

"Exactly. The death of the cat paradox teaches you about life. And once you've discovered that the consciousness that can resolve the cat paradox has got to be a transcendent one consciousness outside the space-time-matter-motion world, and that you are that consciousness, how can you not recognize your power—that you create your reality?"

"I still don't quite get it. If I am creating reality moment to moment, and, I suppose, others like me are doing it too, how do we manage to create basically the same world?"

"Very good question. The macro-level of reality, the objects around us, are massive; their possibility waves expand very sluggishly. So in between what you see and what somebody else sees, there is little new possibility of creation. So you basically see the same things, at least as far as the material world is concerned."

How Does the One Become Many?

"Ah, that brings me to my next question," you look thoughtful again. "If it is all one consciousness, how does the one become many?"

"Good question. In a quantum measurement, a subject-object split is created. The objects are experienced as independent and separate from us. A collapsed object is no longer nonlocally connected either with us or with other objects. But the subject remains unitive. Unfortunately, as you collect experience (don't blame yourself, if you didn't collect experiences, how would you get a reference point for yourself?), it takes a toll. You develop an identity—everyone does. So as a result of memories and habits, conditioning really, we take on a character, a personality. Now the subject has also multiplied."

"But this is all appearance, right? You said consciousness identifies itself with the subject-pole of an experience, and then that subjectivity multiplies further because of conditioning. If this is all appearance, there must be a way out of this."

"Of course there is. The tangled hierarchy is your creation, albeit in a nonordinary consciousness. If a salesperson comes to your door and tries to sell you a unicorn, and says, 'What will it be, cash or charge?' you are not fooled by his or her attempt to create a tangle. You slam the door, you jump out of the system. Similarly, we can also jump out of this world of separateness. But that's another story, my dear Watson..."

CHAPTER 20

From Deep to Deeper to Deepest Ecology

The philosopher Erne Ness coined the phrase *deep ecology* and since then it has influenced the current new-age thought in the West considerably. The idea is to go deep in our definition of ecology. The "shallow" ecology of modernism has done us in. It puts humans above nature and prompts us to regard nature as something to be used for our benefit alone, something to be conquered and manipulated. Instead, deep ecology asks us to give up the implicit mind-body dualism of the philosophy of humans over nature, and instead see that we are also part of nature, we are also determined by the same laws as the rest of nature. Moreover, we are interconnected with nature. We are part of the living nature and its ecological cycles; we share nature's resources along with other creatures. This interconnection should remind us to respect and preserve nature, and not pollute and destroy in our vain search for happiness.

But if we give up the philosophy of modernism, and with it the idea of free will, and adopt instead the idea that we are determined by the laws of physics, then how can we say that we have any intrinsic value or meaning in our lives? In order to avoid this existential despair, deep ecologists resort to the philosophy of holism—that the whole is greater than the parts.

The physicist Fritjoff Capra wrote a book called *The Turning Point*, in which he invoked systems theory to justify why the whole should be greater than its parts and why, although the material constituents of nature, the elementary particles, do not have any

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intrinsic value, their sum total, the whole, looked upon as a network of interacting systems, may be able to emerge with intrinsic value, even the sense of what we call spirituality.

This, of course, is a different version of spirituality than what spiritual traditions, the great religions of the world, propound. For the traditions, fundamental to spirituality is the idea that we are more than the obvious physical body and the mind, we are also a transcendent spirit—a divinity. Here the word "transcendent" means "within all this and outside all this," to quote the East Indian Upanishads.

But there is a spiritual philosophy called pantheism or animism that sees the "spirit" as an immanent entity; it sees all nature to be alive with spirit. In the transcendent philosophy, spirit is in nature also, but that's not all of spirit, there is also spirit that transcends nature. But to modern thinkers, especially scientists, the idea of transcendence seems like dualism, spirit separate from nature (which, unfortunately, is also how popular versions of the great spiritual traditions see spirit). Thus pantheism seems like a better alternative, and many scientists of the new age have adapted this philosophy to their thinking and to their exposition of the philosophy of deep ecology.

The Nobel laureate physical chemist Ilya Prigogine and the proponents of chaos theory have propounded the idea of "order within chaos" in suggesting how nature may come alive with immanent spirit and intrinsic value. Prigogine proposes the overthrow of the Newtonian second law of motion, and even of the Schrödinger equation (which are physics of being) altogether to opt for a new physics of becoming. In the physics of being, an arrow of time cannot be defined; time remains a two-way street. Past, present, and future coexist in being, and, thus, strictly speaking, there is no evolution, no becoming. In the physics of becoming that celebrates the irreversibility of becoming, Prigogine has been able to demonstrate in some simple systems the emergence of holistic order in spite of chaos. For complex systems like us, some of this order may very well correspond to consciousness, spirituality, free will—so says Prigogine, anyway. The proponents of chaos theory, determined chaos, have been able to demonstrate order within chaos even within an overall Newtonian determinism. In chaotic systems, determined does not mean predictable, and unexpected order can arise in the midst of chaotic movement. If it is unexpected, such order may very well be interpreted and experienced as free will, as spirituality.

Thus Prigogine and the chaos company have developed a scientific model for deep ecology, but the existential challenge of despair still remains. Newtonian determinism holds us to be determined mechanical machines, and this is further supported by genetic determinism—we are determined by our genes—and behavioral determinism—we are the products of environmental conditioning. Even if there is order within chaos, and sometimes the order may be experienced as a spiritual interconnectedness, the underlying dynamics (holistic or reductionistic) of matter prevail, and there is no transformation that can be brought about by our intentions of living integrally with the ecological community to which we belong. Without any mechanism toward transformation, and here holistic metaphysics is as promissory as the reductionistic one, how can we change? And that means we are back to existential despair.

The truth is, the interconnectedness proposed by Capra, Prigogine, and the chaos theorists is a shallow interconnectedness. The truth is, local forces, forces that fall off with

distance (and all material forces are local), can only mediate an interconnectedness between a network of systems, chaotic or not, that is basically local. Instead, the physicist David Bohm propounds a more versatile and potent interconnectedness via quantum nonlocality. In Bohm's causal interpretation of quantum mechanics, the wave-particle relationship is such that the wave can be seen to guide the particle (whose behavior may now be often quite non-Newtonian and bizarre) through the quantum potential, a spooky action-at-a-distance that does not die off with distance. A network of interacting quantum systems, in Bohm's model, would have a potent interconnectedness via the hidden order of the waves (Bohm calls it the implicate order). So the explicate particle order of manifest beings may look disconnected except on occasions of Einstein-Podolsky-Rosen (EPR) quantum correlation effect, but underneath the interconnectedness in the implicate order still holds. This is a deeper ecology than the deep ecology of Capra or Prigogine or chaos theorists.

A static example of Bohmian interconnectedness is a hologram where every part retains the information contained in the whole, albeit with poor resolution. Thus in the explicate order, objects may appear isolated and individual, but they retain the holistic potency of the interconnected whole of the implicate order. Neurophysiologists such as Karl Pribram have supported this kind of deep ecology by constructing interesting holographic models of the human brain memory.

Thus, Bohm's deep ecology is deeper than Capra's or Prigogine's, but is it deep enough? Deep enough for us to think beyond the existential despair? The answer is still no. There is still no mechanism for transformation, no mechanism by which deep ecological being can be brought about starting with the Newtonian/sociobiological/behavioral deterministic creatures that most of us are, for which there is plenty of evidence.

It is clear that the deepest ecology must be one that not only has interconnectedness but also the ability of the inhabitants to transform, to be able to live in spiritual harmony that the underlying interconnectedness dictates.

But so long as the permitted interactions between our systems are material interactions alone, so long as all the cause of change comes from the interacting elementary particles at the base level moving upwards, to atoms, to molecules, to neurons, to the brain, and finally to consciousness, us, we are stuck. So long as causally continuous mathematics, algorithms, define our being and becoming, we are subject to the ups and downs of orders and chaoses of material dynamics, irrespective of our intentions, and struggle for a transformed being. For transformation we need downward causation. We need the modernist concept of free will, but without dualism.

We can and we must introduce downward causation in quantum physics, says the mathematician John von Neumann. Quantum mechanics defines material objects as waves of possibilities, mere superpositions of this or that potentia, not actualities, not the solid objects that we see around us. How do the objects as mere possibilities become the actual events of concrete, of our experience? Downward causation by our consciousness, proposes von Neumann. The elementary particles, the atoms they make, the molecules, the neurons, even the brain, all remain as possibilities until we, the observer, bring them to actuality with our measurement, using our ability of downward causation, free will. The transition from possibility to actuality, or the collapse of the possibility wave to the actual particle, is an act coming from the freedom of choice of our consciousness, because no

algorithm for it exists within quantum mechanics, no algorithm for it can be given staying strictly within quantum mechanical mathematics.

Downward causation via quantum measurement has the decided advantage of quantum nonlocality as well. Quantum interconnectedness is now ever deeper because nonlocal consciousness has entered the picture. And more. Quantum collapse is discontinuous.

This discontinuity is crucially important to recognize before we can contemplate transforming our living in harmony with an ecological worldview. The fact is, spiritual traditions have been telling us about love and harmony in living with our fellow ecological partners for millennia, but few of us have been able to change. Why so? Because such changes, the much-heralded transformation of our being, comes about via acts of discontinuous quantum collapse. We cannot make them happen by wishing, by even meditating, by no continuous maneuver at all. Instead, we have to depend on a process that includes discontinuity, and few have understood or trusted this process in the past. Now quantum physics is paving the way toward a new understanding, paving the way for transformation *en masse*, so that we truly may become ecological beings, not just talk about it.

Bibliography

Bohm, D. *Wholeness and Implicate Order*. London: Routledge and Kegan Paul, 1980.
Capra, F. *The Turning Point*. NY: Simon & Schuster, 1982.
Prigogine, I., and Stengers, I. *Order Out of Chaos*. NY: Bantam, 1984.

CHAPTER 21

The Reconciliation with David Bohm's Physics

I have mentioned David Bohm's nonlocal hidden variable theory before (see Chapter 14). In this chapter, I (in collaboration with physicist Mark Comings) argue that Bohm's theory is better interpreted with collapse of the wave function (and therefore, consciousness) brought into the arena. Bohm often expressed his concern, and even lamented, that his theory of reality did not include consciousness. Indeed, he worked hard at including it. In my view, his so-called causal interpretation of quantum mechanics already includes consciousness.

Bohm's basic idea is to represent the situation of quantum mechanics with a wave piloting a particle, an idea he took from Louis de Broglie himself. However, whereas de Broglie envisioned a quantum object as a physical wave piloting a physical particle, Bohm's waves are not physical waves. Instead, they are fluctuating waves of possibility whose average behavior over some characteristic time satisfies the Schrödinger equation. The wave guides the particle via the nonlocal quantum potential.

Now we need to be a little technical. By writing the wave function as a product of two quantities—the amplitude (whose square gives us the probability of finding the object in a given region of space) and the phase, Bohm recovers Newton's equation for a particle with coordinate x (and velocity v) evolving in a trajectory. The trajectory then is claimed to represent the real world of Newtonian vintage. The wave guides the trajectory through the so-called quantum potential in addition to whatever other force field the object is under.

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This quantum potential is non-local and the effect of it continues even in empty space. So, for example, Newton's first law that objects travel in straight lines in the absence of any external forces no longer applies.

In the case of the double-slit experiment, for example, Bohm's particle equation can show us curved trajectories of how a particle may be able to go through one slit and still arrive at classically forbidden places on a fluorescent plate. How does the particle know that the other slit is open and veer itself to the quantum mechanically allowed places? Through the nonlocal influence of the quantum potential, which acts as a source of "active information."

Because the particle equation has been derived from the Schrödinger equation with only a little bit of redefinition of momentum (so that both momentum and position of the particle are simultaneously definable), it is assumed that Bohm's theory is equivalent to quantum mechanics (although there are some subtle differences). Bohm and his collaborators think that this is a causal interpretation of quantum mechanics because a classical trajectory has been calculated. But this thinking is fallacious.

The classical equation in Bohm's theory is not, strictly speaking, a space-time equation because the quantum potential depends on the wave function, which has no space-time existence until it is collapsed. Thus, the causal discontinuity of quantum mechanics still remains, because without wave function collapse, without knowing where the particle ends up, Bohm's method cannot be applied to calculate the particle trajectory.

Through sheer sophistry, Bohm and his collaborators avoid dealing with the fundamental problem of quantum measurement—why only one of the possibilities become actual in a measurement while all others do not. As Henry Stapp has already pointed out, the measurement problem is "bypassed" by assuming that the quantum potential forces the particle into one channel, although the other channels of the wave function remain empty. Stapp also points out that only the probability is testable even in Bohm's theory (as in quantum mechanics), not the quantum potential. In Stapp's opinion, a theory such as Bohm's that does not add anything tangible to quantum mechanics, but only adds extra elements on the basis of classical intuition, is not worth much investigation.

However, over the years Bohm's theory has enjoyed a certain popularity and should not be dismissed off hand. Like Stapp, I believe that the measurement problem is not solved by Bohm's interpretation of his mathematics. But suppose we interpret Bohm's equations without any classical prejudice. What then?

Suppose we agree, as logic dictates, that Bohm's calculations are pertinent only in the aftermath of the wave function collapse, only when we know where the particle has ended up in a given measurement. Bohm's method then enables us to calculate the entire trajectory leading to the point of collapse. Thus the collapse can be seen to entail not only the possibility wave collapsing to a particle at the point of collapse, but the collapse of the entire trajectory going backwards in time.

Notice that, in this view, discontinuity of collapse remains. Out of all the quantum possibilities, a unique actuality is discontinuously chosen (by our observation and in our experience). But now we can go back in time and reconstruct the pathway of events in space-time leading to the event of collapse. We cannot relive these past events in the present moment, but there may be (fossil) remnants of these events now that may enable us to verify the validity of such a reconstruction.

Bohm has always emphasized how beautiful his theory is for understanding and appreciating quantum nonlocality as the action of the quantum potential. Yet Stapp's criticism cannot be denied: the quantum potential is not observable. But under the action of the quantum potential, the calculated trajectories of Bohm's theory have unusual characteristics. Could these unusual characteristics be observable?

One such unusual characteristic is faster-than-light propagation. In the phenomenon of quantum tunneling, the time taken by a quantum object while going through the tunnel can be measured, and such measurements are now revealing a compelling case of faster-than-light propagation. This, in my opinion, proves the usefulness of Bohm's theory.

Is such faster-than-light propagation against the theory of relativity? Hardly. We still cannot directly observe the object in its faster-than-light condition. Any attempt to observe it will destroy the tunnel. The speed-of-light limit applies to trajectories that are directly observable; the trajectories of objects in tunneling a la Bohm are unobservable, so no challenge of relativity theory is necessary.

Implicate and Explicate Order

In his philosophical writings, Bohm also leaves us with the impression that reality comes to us via two orders, one implicate (or implicit or hidden), which guides the behavior of what is explicate (or explicit), the order that we see, the order that is causal and objective. With a reinterpretation of Bohm's work, his philosophy of implicate and explicate orders also needs to be modified.

The implicate order is easily seen as the transcendent order of quantum potentia where ontologically the quantum wave functions or possibility waves reside. The explicate order, however, is neither causal nor objective. It is not causal because there is no way to calculate the trajectories of objects in it *a priori* and thus there is no reason to assume that they exist *a priori*, before the discontinuous wave function collapse. It is not objective, because the result of wave function collapse happens in our experience; collapse cannot be eliminated and neither can the observer from our description of reality. The collapse of the present event, however, brings about the collapse of an entire pathway of events leading to the present moment going backwards in time. These past "events" cannot be lived now, but certain remnants or memories of these events elicited now can reveal their implicit existence.

In the human dimension, the idealist interpretation is being used to construct a new science within consciousness that can treat not only the material world, but also our internal mental world. For example, a theory of creativity (see Chapter 23). A creative experience is sudden and discontinuous, a quantum leap, according to this theory. Although many creative people describe their creative acts this way, a considerable amount of controversy exists showing a lot of disagreement with this position. Bohm's ideas can resolve the controversy. Although discontinuity dominates the creative experience, after the event, if there is enough memory from the *ex-post-facto* collapsed past, then one can reinterpret one's experience as a continuous one, especially if one's prejudices are disposed that way.

In conclusion, with this straightforward interpretation of Bohm's work, I think we

can see that collapse of the wave function and consciousness as the causal agent for collapse remain basic in any interpretation of quantum mechanics and any understanding of quantum measurement.

Bibliography

Bohm, D. *Wholeness and Implicate Order*. London: Routledge and Kegan Paul, 1980.

Bohm, D., and Hiley, B. *The Undivided Universe*. London: Routledge and Kegan Paul, 1997.

Goswami, A., and Comings, M. "Consciousness and Quantum Measurement," *Bulletin of Science within Consciousness*, vol. 4, pp. 2-4, 1999.

Stapp, H.P. "Quantum Nonlocality and the Description of Nature." In J.T. Cushing and E. McMullin (eds.), *Philosophical Consequences of Quantum Theory*. Notre Dam, IN: University of Notre Dam Press, 1989.

CHAPTER 22

The Gifts of Quantum Physics

The success of Newtonian physics, especially the technological success, has been one of the greatest blinders that humankind has ever put on. The reintroduction of discontinuity, nonlocality, downward causation, and tangled hierarchy in our worldview is the greatest gift of quantum physics.

Let's review the subject of continuity versus discontinuity. If you close your eyes for a while and then open them, how does the world look? Most often, very similar. Once in a while a tornado may drastically change everything in your environment while your eyes were closed, but even then you'd have noticed some warnings even with closed eyes. Thus, the assumption of continuity seems entirely reasonable. For physicists, the assumption of continuity is a boon because it enables them to use mathematics to describe change, and thus predict and control change.

In contrast to continuous change, examples of discontinuous change are truly hard to find. Even our metaphors for discontinuous change, tornadoes, hurricanes, and lightning bolts, on closer examination show signs of continuity. But truly, we are barking up the wrong tree! Quantum correspondence principle clearly indicates that in the macro world of our material experience, classical determinism prevails and all signatures of discontinuity are camouflaged.

To find true-blue examples of discontinuity, we have to look inside. We have to look at our subjective experiences. And the prime example of discontinuity there is our creativity.

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The Discontinuity of Creativity

What is creativity? It is the discovery or invention of something new of value, but what is new? Is a new juxtaposition of letters and words a creative act? On closer thinking, we recognize that the new in creativity must consist of new *meaning*.

Now, new meaning can consist of an invention, in which case the new meaning is explored within already known contexts of thinking. This kind of creativity I call *situational creativity*. An example is the creativity expressed in writing a romance novel. Scientific inventions fall in the same category.

Meaning depends on the context in which we investigate it. To see that meaning changes with context, consider the word "ass" in the two sentences:

> You are an ass if you refuse to understand the importance of meaning in creativity.
> Get off your ass and come over here!

The greatest acts of our creativity consist of the shift of context, the exploration of meaning in a brand new context. I call these the acts of *fundamental creativity*. These are the acts that we call discovery, as opposed to invention. To see what a shift of context is like, consider the nine dot problem: Review the array of nine dots as shown in Figure 22.1. What is the minimum number of straight lines you need to connect the dots without raising your pencil? Many people answer this problem with five, but a better answer is four (Figure 22.2). Why do people answer five? Because of the habit of thinking that we have to stay within the boundary defined by the dots. The better answer lies in the shift of context to thinking that we are permitted to roam outside of the space defined by the

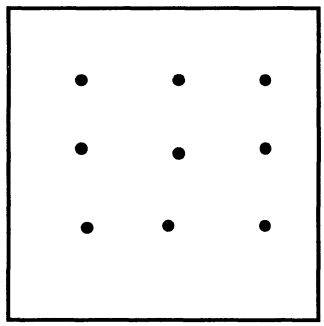

Figure 22.1
What is the minimum number of lines needed to connect the dots without raising your pencil?

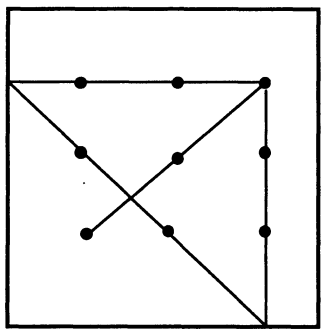

Figure 22.2
Many people would answer five, but the best answer is four.

dots. Nowhere does the problem restrict such movement. In the same vein, people in Einstein's time always thought time to be absolute, independent of motion. This habit of thinking stymied even Einstein when he was looking to reconcile Maxwell's electromagnetic theory with Newton's mechanics. Only when Einstein's creativity allowed the discontinuous shift of context about the nature of time—that time is relative, it depends on motion—was he able to solve his problem and discover such wonderful facts as $E = mc^2$.

This discontinuity of Einstein's creativity is beautifully captured in a Sidney Harris cartoon in which Einstein, baggy pants and all, stands before a blackboard on which $E = ma^2$ is written and crossed out and below that, $E = mb^2$ is written and crossed out. The caption reads, "The creative moment." And we laugh because intuitively we know that great creative truths are not discovered with reasoned steps like this.

And if you think that creativity is highly esoteric and beyond your experience, think again. It is fact that when we are children, creativity is a common occurrence as we learn (re-discover) such wonderful contexts of thinking as seeing meaning as we read a story or count numbers. My own earliest creative experience that I remember is my discovery of the meaning of numbers. First, my mother grilled me to count up to a hundred, but I didn't have an inkling of what was going on. Then she started pointing things out to me—two cows, two fingers, three pencils, three heads, and things like that. After a while, one day, I got it—the numbers described certain configurations of things irrespective of what the thing was! Mathematically, this is the concept of a set, although I was not told that at the time. But I still remember the thrill of that discovery!

Still, scientists who have only a Newtonian understanding of science fight the idea of discontinuity in creativity tooth and nail. Really, it takes quantum physics to appreciate discontinuity. When you truly understand and accept that when electrons jump orbits in the atom, they do not go through the intervening space, they just disappear in the upper orbit and instantly reappear at the lower, you have no difficulty in entertaining the idea that creative insights must similarly be quantum leaps in thought, quantum leaps of meaning or in the contexts of meaning.

Creativity in the outer arena is not the only instance of discontinuous movement. There are also the transformative experiences that I call inner creativity, discontinuous change in the way we live. Quantum physics enables us to make reliable models of transformation that can enable us to not only see ourselves as ecological beings, but actually live that way. This is why I consider quantum discontinuity to be a wonderful gift to us.

Nonlocality

To recap, the concept of locality is that all interaction between two objects occur through the intermediary of some force or field or some signal, going from one body to the other, bit by bit through the intervening space taking a finite time. In contrast, nonlocality is basically action-at-a-distance—an influence that propagates instantly from one body to another without a signal going through the intervening space.

We now know that all forces, all the four fundamental interactions of nature (gravitational, electromagnetic, and weak and strong nuclear forces), are local. So locality dominates not only macro nature but also micro nature (except in those special cases that we

call EPR correlation) as far as the material world is concerned. Once again, we have to look at our subjective experiences to find instances of nonlocality.

You are thinking of a friend, and suddenly the telephone rings. It is your friend on the phone. A mother wakes up from a dream with the feeling that her son is sick, and a telegram arrives carrying that message. These instances could be coincidences, but a more appropriate description is what the psychologist Carl Jung called synchronicity—meaningful coincidences due to a common cause of nonlocal influence—with the tacit approval of the physicist Wolfgang Pauli. And indeed, Jung has now been vindicated by the many instances of experimental verification of his idea.

Let's consider distant viewing experiments as one of these instances. Typically, a psychic looks at some outdoors scene that is randomly selected by a computer within a double-blind scheme, and his or her partner draws a picture of the scene from a distance—with no local signal mediating any communication between them. These cases do not require anything but a cursory look at the figures drawn to see that something extraordinary is going on, but today, the experimenters of distant viewing uses computer-matching to shut out all objection of subjectivity against matches made with distant viewing.

Even so, our prejudice of locality is so strong that many people, scientists especially, remain unconvinced by the data. You may think that the Aspect experiment (see Chapter 14) should have settled this issue. After all, if photons can do a synchronistic dance with a clear display of phase-match, why can't people? It is not so simple to generalize, and the reason is subtle.

The truth is, the strict materialist can derive some consolation from the fact that no information can be transferred via quantum nonlocality per se. This is called the Eberhard theorem because the physicist Philippe Eberhard proved this notion formally, but the idea is quite easy to understand.

Why can't information be transferred riding the horse of quantum nonlocality? Information transfer requires the detection of two consecutive, correlated events at the same detector location. In Aspect's experiment, what one detector detects is correlated with what the other detector detects at a distance, but there is no correlation between one detection event and the subsequent one at the same location—events in the same detector location are random (see also Chapter 14).

So quantum nonlocality is not enough. Quantum within consciousness solves the problem by supplementing quantum nonlocality with the idea that consciousness collapses quantum waves of possibility into actual events, and the idea that conscious intention can correlate two quantum objects and keep them correlated through many events.

The idea that consciousness collapses quantum possibility into actuality is the subject of previous chapters and is not new. For understanding the idea that conscious intention can correlate two quantum objects, consider the classic experiment of Grinberg-Zylberbaum et al.

The recent experiment by the University of Mexico neurophysiologist Jacobo Grinberg-Zylberbaum and his collaborators supports the idea of nonlocal, signalless communication between human brains—this experiment is the equivalent for brains of the Aspect experiment for photons. Two subjects are instructed to meditate together for a period of twenty minutes in order to establish a "direct communication" via conscious intention. Then they enter separate Faraday chambers (metallic enclosures that block all

electromagnetic signals) while maintaining their meditative states of direct communication for the duration of the experiment. They are each hooked up to individual EEG machines to measure their brain activity. One of the subjects is shown a series of light flashes that produce an evoked potential, a unique electrophysiological response of the brain to a sensory stimulus, which is measured by the EEG machine (Figure 22.3(a)) connected to his or her brain.

Amazingly, in about one in four cases, the unstimulated brain (as measured by the EEG) also shows an electrical activity, a "transferred" potential quite similar in shape and strength to the evoked potential (Figure 22.3(b) and (c)). Control subjects who are not correlated and experimental subjects who, by their own reports, do not achieve or maintain direct communication never show any transferred potential (Figure 22.4). The straight-

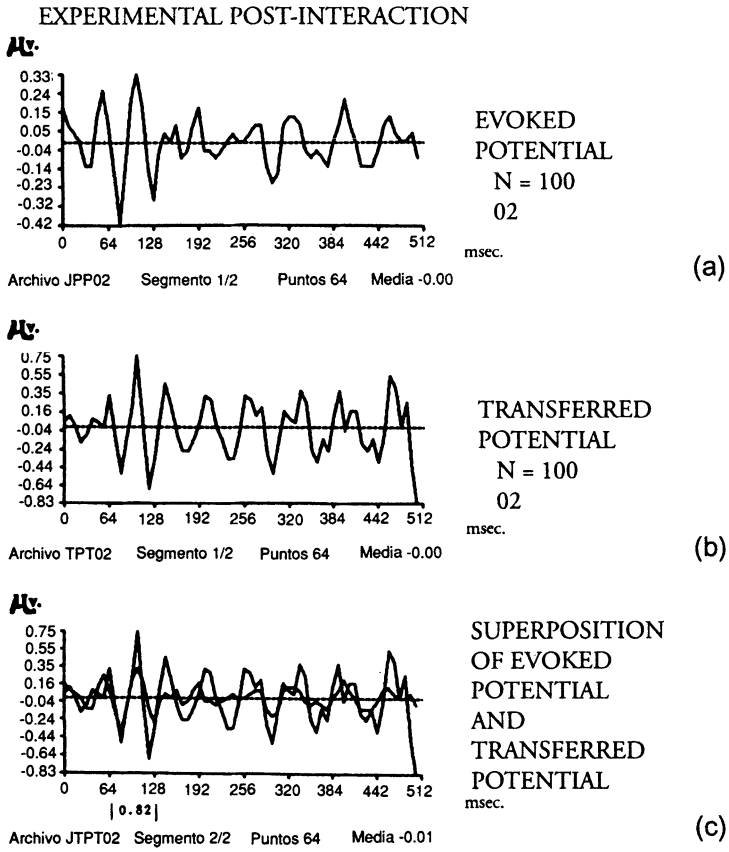

Figure 22.3
(a) EEG reading of electrophysiological response in the brain to a sensory stimulus.
(b) EEG results for the brain which is not stimulated—electrical activity measured in about one in four cases.
(c) Superposition of the two readings; there is a 71% overlap.

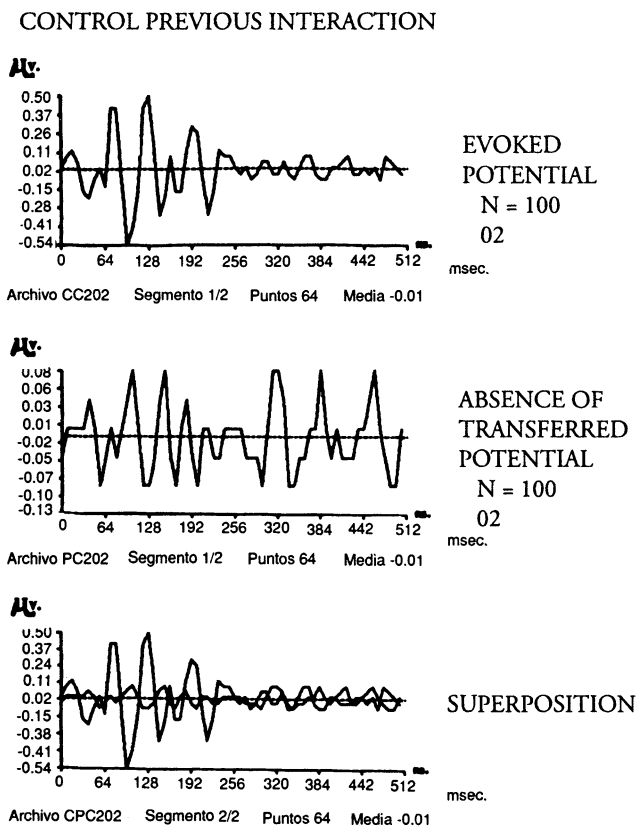

Figure 22.4
EEG readings for electrical activity for control group.

forward explanation is quantum nonlocality—the two brains act as a nonlocally correlated quantum system. In response to a stimulus to only one of the correlated brains, consciousness collapses similar states in the two brains; hence the similarity of the brain potentials.

The striking similarity between the correlated brains of this experiment and the correlated photons of Aspect's experiment should be clear, but there is also a striking difference. The similarity is that in both cases the initial correlation is produced by some "interaction." In the case of the photons, the interaction is purely physical. But in the case of the correlated brains, consciousness is involved. For correlated photons, as soon as the possibility wave of one is collapsed by measurement, the objects become uncorrelated. But in the case of the correlated brains, consciousness not only establishes correlation initially, but also maintains the correlation over the duration of the experiment. To get a clear evoked potential, experimenters typically use an averaging procedure over 100 or so light flashes in order to eliminate the "noise." But the brains do not become uncorrelated as soon as one observer sees a light flash. The only conclusion is that consciousness reestablishes the correlation every time it is broken.

This difference between correlated photons (as in Aspect's experiment) and correlated brains (as in Grinberg-Zylberbaum's experiment) is highly significant. The nonlocality of correlated photons, although striking in terms of demonstrating the radicalness of quantum physics, cannot be used to transfer information, according to the above-mentioned Eberhard's theorem. Each photon that one experimenter sees in a stream of photons is correlated with its partner, which is observed by another experimenter. But there is no correlation between the states of the photons within the stream observed by one experimenter. These states are randomly distributed, hence they can carry no message. But in the case of the correlated brains, since consciousness is involved in establishing and maintaining the correlation over the period of the entire experiment, Eberhard's theorem does not apply, and message transfer is not forbidden. Consciousness chooses collapsed events in the brain of each observer not randomly, but in a correlated fashion to convey message and meaning.

There is now some data collected by the parapsychologist Dean Radin that in the presence of strong intention, random number generators show deviation from randomness. The data was gathered first during the O.J. Simpson trial with a very large TV audience. Indeed, the times when the courtroom drama was at its high point (as judged by a group of psychologists), were when also the random number generators deviated from randomness the most.

One more comment. The conscious intention, the agreement of the two subjects, is crucial for the success of any telepathic communication. However, the intention is not an egoic one; simple thinking and willing will not do. Instead, it is a letting-go to a state of consciousness beyond ego, where the two are one. Jesus knew about this since he said, "If two of you agree down here on earth concerning anything you ask for, My Father in heaven will do it for you." Significantly, the Greek word for the verb "to agree" is *symphonein*, which is the etymological root of the word symphony. To agree is to vibrate in phase, quantum correlation. Isn't this what we are seeing in the coherence of the brainwave data in Grinberg-Zylberbaum's experiment?

One aside. Materialist scientists sometimes complain that they more often than not fail to replicate experiments on telepathy, even with well-known psychics. I think they are missing one of the key ingredients in such experiments: conscious intention. Consciousness is one. Perhaps closed-minded skepticism of the experimenter interferes with conscious intention so that consciousness neither correlates the psychics nor collapses (nearly) identical possibilities in their brains in the presence of such hostility. The parapsychologist Marilyn Schlitz at the Institute of Noetic Sciences has carried out experiments with a skeptic collaborator that confirm what I am theorizing. Schlitz has done several series of experiments in which she finds the positive result that a subject, when watched via closed-circuit TV unbeknownst to him or her, shows changes of behavior. When the same experiment is repeated with identical methodology by her skeptic colleague, he gets null result.

In the sixties, there was a science fiction show called *Star Trek* in which there was an episode that is very telling. I have mentioned it before—a man did something wrong and had to be punished, but, of course, the days of violent punishment were over. So they punished him by banishment to a lonely island. So far so good? But hear this: he will be able to spend his time in the company of many beautiful women, but these women are androids. So why is this a punishment? We, the viewers, still see it as punishment because

intuitively we know that consciousness is nonlocal. Local contact with machines, however pleasurable, doesn't ultimately satisfy, because they lack this nonlocal connection that only other living beings can give. This is what deep ecology is really about.

Downward Causation

The third important gift of quantum physics in sorting out our experiential reality is what the psychologist Donald Campbell called downward causation. This is an appropriate phrase for describing the event of collapse of quantum possibilities by consciousness. You remember that in the conventional, classical view, consciousness is a brain phenomenon—elementary particles make atoms, atoms make molecules, molecules make neurons, neurons make brain, brain makes consciousness. In this view all causation is upward causation moving up from the elementary particles whose interactions are the only cause of everything. But in the quantum view, all things, all the material levels of the hierarchy above, the elementary particles, atoms, molecules, neurons, even the brain, remain as possibilities, and the supposedly highest level—consciousness—is needed to collapse the possibilities into actuality. It is as if consciousness was acting downwards, and hence the phrase downward causation.

I hope you can see that as important as discontinuity and nonlocality are as quantum gifts, without downward causation they would not have much tooth. It is a fact that ultimately creative and paranormal experiences are acts of downward causation. To be sure, their discontinuity and nonlocality, respectively, are important, but even more important is the aspect of downward causation via quantum collapse of the new meaning, and synchronicity, respectively.

Most importantly, without downward causation, without free will or freedom of choice, we could never transform, we could never choose harmony or order over disharmony and disorder.

Is there any evidence that quantum collapse of possibility waves is really an act of downward causation by consciousness? There is. The physicist/paranormal researcher Helmuth Schmidt has done a beautiful experiment that threatens to conclusively demonstrate downward causation and the importance of conscious observer in a dramatic way.

The difficulty of demonstrating downward causation is the difficulty of drawing the line experimentally as to where exactly the collapse of the wave function takes place—at the macro measurement apparatus, at the observer's brain, or consciousness. Do waves of possibility really wait in limbo until a conscious observer finally looks at them? If the looking by the conscious observer is active, and not benign, then a demonstration is possible, because surely if the apparatus has caused the wave function to collapse, then any active, conscious influence of the quantum possibilities would be impossible.

So Schmidt uses psychics with psychokinetic powers (with the power of affecting matter with their consciousness) for this purpose. Schmidt has been experimenting with the psychic ability to influence random number generators in which quantum random radioactive decay is converted by a computer into an array of random binary numbers, zero and one. In a long sequence, the number of zeroes and ones should be equal, but Schmidt's psychics try to get more zeroes or more ones, under Schmidt's command. Over

the years, Schmidt has quite a bit of data demonstrating the psychokinetic ability of his psychics.

In the experiment under discussion, Schmidt introduced a time lag in his experiment. The radioactive decay took place, the computer analyzed and arranged the data in a sequence of random numbers, and even a printout was made of the data, with one caveat. No conscious observer looked at the computer screen or the printout. Instead, the sealed printout was sent out to an independent observer (who did not open the envelope). Three months later, the independent observer, using his or her own personal, random criterion asked the psychic to influence the random number generation in a chosen direction. Only then did the psychic look at the computer monitor and try to influence the randomness of the radioactive decay and hence the randomness of the numbers.

And surprisingly, in four out of a total five experiments, the psychic succeeded in influencing the results of a random number generator in the direction chosen by the independent observer, even three months after the decay had supposedly taken place as verified by the independent observer from the printout. How is this possible? Was the psychic changing the past? A more succinct explanation is downward causation: the data remained in limbo until the psychic looked at it on the computer monitor. To further confirm this, in a control experiment in which the printout was intercepted and thoroughly looked at (unbeknownst to the psychic), the psychic was unable to influence the data away from randomness.

Adding up all the cases, this was a three standard deviation result, impossible not to take seriously. Not only does the experiment demonstrates downward causation, but, like the Grinberg-Zylberbaum experiment, it also demonstrates that quantum effects are important even at the macro level of our reality. We can sort our macroscopic experiences using the principles of quantum physics. This is an unprecedented expansion of science to include our subjective experiences. I call it "science within consciousness," because its basis lies in the primacy of consciousness. The application of this new science to biology is the subject of Part 6 of this book.

Tangled Hierarchy

The fourth gift to us that idealist quantum physics brings is tangled hierarchy. And like discontinuity, nonlocality, and downward causation, this important aspect of our being is also well hidden underneath our conditioned patterns that make our ego-identity into an apparent simple hierarchy. We co-create the world tangled hierarchically, but because of the ego obscuration think of ourselves as the creator, as the actor, as the doer. And our relationship with the world suffers because of this simple hierarchy.

But those of us who are fortunate to have intimate relationships with other sentient beings rediscover tangled hierarchy in the form of what we call unconditional love. Unconditional love is the basis of altruistic behavior—something that our sociologists must acknowledge because of overwhelming data supporting it, but cannot explain in terms of their behavioristic or sociobiological gene-based models. In quantum thinking, no explanation of unconditional love is needed; it is our natural condition because of the tangled hierarchical nature of the quantum self. All we have to do is remove the ego obscuration.

So quantum physics is giving us these gifts with which to sort out our experiences and trust them. The next question is, How do we manifest these gifts in our lives? The answer is, Through creativity. This is the subject of the next chapter.

Bibliography

Grinberg-Zylberbaum, J, Delaflor, M., Attie, L., and Goswami, A. "The EPR Paradox in the Human Brain: The Transferred Potential." *Physics Essays*, vol. 7, pp. 422-428, 1994.

Schmidt, H. "Observation of a Psychokinetic Effect Under Tightly Controlled Conditions." *Journal of Parapsychology*, vol. 57, pp. 351-372, 1993.

Radin, R. *The Conscious Universe: The Scientific Truth of Psychic Phenomena*. HarperCollins, 1997.

CHAPTER 23

Quantum Creativity

Creativity is our greatest gift, and some of our best moments of life are those engaged in creative acts. In every field of human endeavor, it is now generally recognized that real change comes from the act of creation by individuals such as Georgia O'Keeffe, Albert Einstein, Rabindranath Tagore, Martha Graham, Wolfgang Mozart, and Thomas Edison. We recognize creative individuals, we recognize their acts of creation, and questions swarm in our heads: What is creativity? Can we ever understand the nature of creativity and the creative process? Would such understanding help each one of us individually to fulfill our creative potential? Can anyone be creative? Can we educate our children optimally for creativity?

Hitherto we have been addressing these questions in a piecemeal manner. But finally we have, thanks to quantum physics, a comprehensive theory that can satisfactorily address all these issues. In the last chapter, we have already dealt with the definition of creativity. In this chapter let's address the rest of the questions.

Situational, Fundamental, Inner, and Outer Creativity

In the last chapter, I introduced the notion of two kind of creativity. Situational—when a new meaning is invented within an already existing context or combination of contexts, and fundamental—when a new context for the investigation of meaning is discov-

A. Goswami, *The Physicists' View of Nature*
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ered. I also proposed further refinement in the taxonomy of creative acts. Mechanistic models of creativity ignore the subjective component of the world. Thus, in these models, talk about creativity makes sense only for fields of external endeavor such as science, literature, music, art, etc. But since we are starting with the ontology based on the primacy of consciousness, the definition of an act of creation can and must be enlarged to include the subjective component of our beings as well.

Mahatma Gandhi made an impact on the entire world culture through his discovery of the effectiveness of nonviolent struggle for freedom against oppression, but his outer acts of creation were intimately connected with his own personal transformation, that he himself became nonviolent to the core. In such acts of personal transformation, when a new context of being is discovered and is manifested into a product (the personality of the creative), we can and must recognize an act of creation. To distinguish from acts of creation in the outer arena (outer creativity), I call this kind of creativity inner creativity.

With this definition–inner creativity is the discovery (and manifestation) of new contexts of living–we can see that children's growing up to be adults falls in the category of inner creativity. Other examples of inner creativity occur in acting and in spirituality.

Within inner creativity also, we can discern acts of fundamental creativity (discovery of new contexts of living) and situational creativity (discovery of new meaning in other people's discovered contexts). The founders of some of the world's great religions, Moses, Buddha, Jesus, and Lao Tsu, are examples of fundamental creatives. While people who have followed their footsteps, St. Paul, for example, are situational creatives. The complete taxonomy of creativity is summarized in Figure 23.1.

The Quantum Nature of Creativity

In the last chapter, we found that creativity takes place not through reasoned steps, but instead through discontinuous leaps, quantum leaps. On closer look, researchers have found that the discontinuous act of creative insight is part of a protracted process consisting of four stages: preparation, incubation or unconscious processing, sudden insight, and manifestation. (However, the stages are not as linear as it sounds.) Among these steps it is easy to make mechanistic models of preparation and manifestation, but not only discontinuous insight but also the role of unconscious processing remain a mystery in

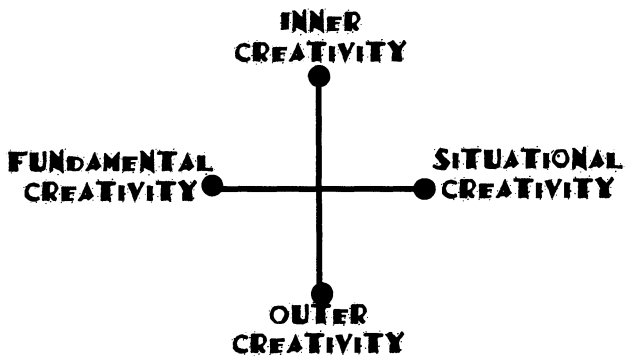

Figure 23.1
The taxonomy of creativity.

these models. Creativity is expressed as an action. Why should inaction–that's what unconscious processing is–be important for it?

Organismic theorists, theorists who see creativity's central aspect as development as in living organisms, insist that there is purposiveness in creativity, final causes drive the creative individual to develop in a certain way. To this mechanists rightly object. The material world, in the classical worldview, evolves causally, through initial causes. There is no room in this worldview for teleological purpose or final cause. So, is there purposiveness in creativity? If so, how?

How important is development in creativity, the pet subject of organismic theorists? Genetic determinism, subscribed to by many mechanistic theorists, proposes traits as the principal issue that determines who is creative and who is not. Can we settle this debate of development versus trait? Can anyone be creative?

I will show that all these controversial questions and issues find answers when we recognize the quantum nature of creativity within a consciousness-based worldview.

Is Creativity a Quantum Leap?

Let's take up the idea of discontinuity of creativity more fully. Is creativity continuous, or is there discontinuity in a creative act, in the so-called Eureka! (as that of Archimedes) experience that creatives themselves refer to as sudden, "like lightning," etc. The three most famous incidents of arrival at creative insight, the cases of "bath" (Archimedes discovers his famous Archimedes principle laying down the law of buoyancy force in hydrostatics while taking a bath), "bed" (Kekule's insight about the ring-shaped nature of electronic bonding in the Benzine molecules came while he was dreaming) and the "bus" (Poincare arrived at one of his important mathematical discoveries unexpectedly while setting foot in a bus), all support the idea of sudden and discontinuous nature of creative insight.

Computer scientists cannot accommodate discontinuity in their models of creativity simply because computing machines are Newtonian in nature, they operate continuously, on the basis of algorithms. The case for the assumption of continuity seems reasonable enough because in the macro nature around us, it is hard to find any example of discontinuity. But quantum physics from the outset has recognized discontinuous movement. The discontinuity in creativity is a quantum phenomenon.

In the Bohr model of the atom, when the electrons jump from one orbit to another, they never pass through the intervening space, giving us a model for discontinuity. The famous phrase "the quantum leap" for discontinuity comes from the Bohr model. When quantum mechanics was discovered to replace the stop-gap Bohr model of the atom, it was confirmed that there are two kinds of movement of objects. In the continuous movement, quantum objects spread as waves of possibility, and they acquire more and more facets. But their collapse to actuality (one facet) is discontinuous movement, a quantum leap.

The continuous movement of quantum objects is caused by material interactions–upward causation. The cause of movement travels upwards from elementary particles to atoms, to molecules, to cells, and finally to the brain. In a quantum measurement, which every act of perception or thinking is, the brain ultimately offers macroscopically distin-

guishable waves of possibility for consciousness to choose from. This choice results in the downward causation event of collapse, which is discontinuous. Thus the idea of quantum measurement in the brain gives us a model of discontinuous creative insight.

Is creativity a discontinuous quantum leap of the brain, then? Creativity is the quantum leap in meaning, but it is easily seen that the brain, being a material machine, cannot process meaning. Like a silicon computer, the brain processes symbols, not meaning. And you cannot reserve some of the symbols for processing meaning, because you would need more symbols for keeping track of the meaning symbols, *ad infinitum*. So we must face it. The carriers of meaning, thoughts, do not belong to the brain. They originate in the mind, of course, but we must recognize that mind is not brain. The philosopher John Searle has termed this turn-around as the "rediscovery of the mind."

This need not raise the specter of dualism. Because if the mind is quantum, if thoughts are quantum movements of possibility waves of the mind, then consciousness can simultaneously collapse the possibility waves of the brain and of the mind. This is a new form of a philosophy called psychophysical parallelism but without dualism because consciousness mediates to maintain the parallelism between the brain and the mind.

So a creative insight is a quantum leap of the mind. Is there evidence that mental thought is quantum in nature? There is plenty of evidence. As the physicist David Bohm first pointed out, thoughts obey an uncertainty principle: we cannot simultaneously ascertain both the content (feature) and the direction (association) of thought. Ambiguous words carry ambiguous meaning in thought when we don't measure them (that is, process them unawarely, which is called unconscious processing). Thoughts do become superpositions of possibilities between measurements. But when we do measure, we find only one meaning, the superposition of meanings collapses.

A telltale sign of the quantum nature of objects is their nonlocality—mutual influence via entangled phase relationship that extends beyond space and time and does not involve signals. The evidence of nonlocality of creative thought may be found in many events of multiple creativity—independent discoveries and inventions of the same product.

Newton discovered the mathematics of calculus in England, but so did Leibniz of Germany without knowing about Newton's work. Schrödinger and Heisenberg discovered the mathematical equations of quantum mechanics in different forms without knowing about each other's work. The difference in form can be explained by the difference of the individual ego structure of the individual creative that plays a role in the manifestation of a creative insight.

The Creative Process and the Importance of Unconscious Processing

As mentioned before, the creative process consists of four stages—preparation, unconscious processing, insight, and manifestation. Preparation is the acquiring of existing knowledge, and manifestation is the finishing of the product based on the insight. These two stages can be seen to be mainly algorithmic. But the middle two stages, unconscious processing and insight, are distinctly nonalgorithmic. They require the quantum to understand them.

The suddenness of insight—the "Ah ha!" experience—is due to the discontinuity of the quantum leap of thought. But why is unconscious processing important? And how is unconscious processing different from conscious processing—preparation?

The second question first. Quantum collapse requires brain-mind awareness. When there is no awareness, there is no collapse of possibilities, and this is the situation when the processing is unconscious—processing without awareness. In contrast, preparation is processing with awareness. To put in another way, preparation is doing, unconscious processing is non-doing. Preparation is active work, unconscious processing is passive relaxation.

Why is unconscious processing important? Quantum waves of possibility spread in between measurement—the collapse events. If we don't collapse thoughts through conscious striving to solve our problem, and additionally, if we feed ourselves ambiguity, we can accumulate quite a bit of uncollapsed superpositions of possibilities in thought. The materialist assumption is that uncollapsed superpositions collapse by chance. But in the quantum-within-consciousness model, no collapse can occur until consciousness so chooses. So when does consciousness choose? When there is a gestalt of possibilities that together presents a solution to the problem.

There is the problem of small probability for hitting the correct combination of ideas from the plethora of possibilities. First, the creative person must make many attempts, so striving is as important as relaxation and unconscious processing. Second, we must remember that fundamental creativity is discovery; the solution is already there in consciousness as a theme that Plato called archetype. When there is a resonant match between the theme and the gestalt, collapse takes place. Resonance, as when soldiers march in unison on a bridge, enhances the probability of collapse. We can see the play of purpose here. Consciousness collapses the creative insight according to its purposive theme that it recognizes, but this is not teleology.

Do probabilities really wait uncollapsed until consciousness chooses? There is now experimental evidence for this. Read the delayed choice psychokinesis experiment of the physicist Helmuth Schmidt described in the last chapter.

Creative Encounter with the Quantum Self and the Flow Experience

Who creates? Superficially this is easy to answer: the creative person, of course. But the creative insight is a phenomenon in which the player is unitive consciousness, the only collapser there is of quantum possibilities. Even so at a subtler level, the role of our conditioned identity, the ego, cannot be denied either. In this way, it is clear that we need to explore further the quantum measurement processes through which the one consciousness (the unitive quantum self) becomes many.

Consciousness chooses actuality from quantum waves of possibility, but only in the presence of brain and awareness. But this leads to the chicken or the egg question—which comes first, choice or awareness? The answer, as elaborated in Chapter 18, is dependent co-arising. In the event of collapse, the choosing self/subject and awareness (of objects) arise simultaneously. Quantum collapse is self-referential.

The self of this self-reference—the quantum self—is universal and its choice is free (constrained only by the quantum probability dynamics of what possibilities are offered). It is also tangled hierarchical. The repeated reflections in the mirror of memory that precede our ordinary experience of learned stimuli converts the creativity of free choice into conditioning, and the tangled hierarchy into a simple hierarchy. The resultant self-identity is our conditioned and simple-hierarchical ego.

But the conditioning never reaches 100 percent, which is the behavioral psychology limit. In that limit all responses are conditioned and the concept of the self is no longer needed. There is no creativity either.

We all operate in the intermediate situation; we are never 100 percent conditioned with respect to any stimulus, we can always say "no" to any conditioned response. We acquire conditioned repertoire in the process of growing up, but on occasion we are able to jump out and engage in creativity. This process of engagement must be looked upon as an encounter between our two self-identities, the ego and the quantum self. It is beautifully depicted by Michelangelo in the ceiling of the Sistine Chapel with Adam (the ego) and God (the quantum self) reaching out to each other (Figure 23.2).

In response to every stimulus, learned or new, the quantum collapse produces the primary event of the quantum self-experience. For a learned stimulus, the reflection in the mirror of memory produces a series of secondary collapse events of progressively increasing conditioning; the time to process these secondary collapse events is responsible for the experimentally observed time-lag of half a second between the arrival of the stimulus and our verbal response to it. Normally, the primary collapse event and the intermediate secondary awareness events remain preconscious in us. In the creative encounter, we literally enter the preconscious and experience ourselves as freer and freer as we move toward the primary awareness event. In this encounter, there is flow (a word coined by the psychologist Mihaly Csikszentmihalyi), and there is joy. The creation seems to create itself.

When we take the encounter into account, we can understand why the creative process is not a linear progression of the four stages. In truth, all creative people know that creativity does not begin with preparation, it begins with intuition, an invitation from the quantum self to investigate, an intimation that we can barely hear. Creative people also know that the journey to the creative insight is best served by alternative striving (preparation) and relaxation (unconscious processing). The striving is dominated by our ego-modality, relaxation takes us toward the unencumbered being of the quantum self. In the process of alternation between this doing and non-doing, suddenly we are able to quantum jump beyond our conditioned repertoire into new recognition and insight.

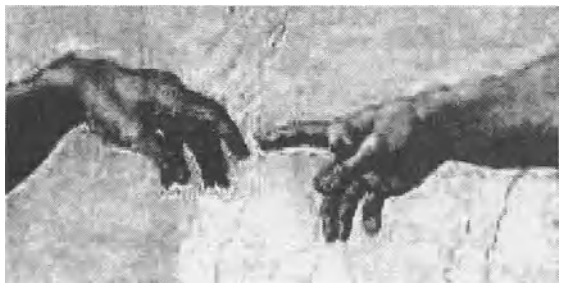

Figure 23.2
The creative encounter of the ego and the quantum self is like Adam and God reaching out to each other, as in Michelangelo's immortal painting.

The quantum leap, as previously mentioned, is a quantum leap of thought, a quantum collapse in our mental body. Simultaneously, a brain state is collapsed, which makes a representation of the insight.

Creativity and Development

Developmental theorists have made important contributions to our understanding of creativity. The quantum theory helps us integrate all the developmental ideas of these theoriests into a coherent whole.

First, a few words about the psychologist Jean Piaget's theory, based on his study of child development, with which the quantum view has complete agreement. Piaget found that the ego-development is a result of a series of alternating creative and homeostatic stages. In the creative stage, quantum leaps of insight (Piaget called them reflective abstraction) lead to addition and assimilation of new contexts in the growing repertoires of contexts of the child. Piaget calls this hierarchical equilibration. During the homeostatic period, the new addition to the child's repertoire is further extended and assimilated through acts of situational problem solving and occasional situational creativity (which Piaget identifies as simple and reciprocal equilibration).

Developmental theorists of creativity essentially try to find an answer to the quintessential question for all of us: Why are some of us creative as adults and others are not, while all of us are creative as children? Mechanistic trait theorists such as Frank Barron posit that special traits (for example, the ability of divergent thinking), ultimately traceable to the genetic endowment, are responsible for the creativity of the adult. But nobody has ever found any special creative trait gene, and there is some empirical evidence that perhaps creative people acquire the traits that serve their creativity while on the job, since there is no one-to-one correspondence between early traits and later-life creativity. Developmental theorists say that the individual and his or her development are the crucial thing. And indeed, developmental theorists have found some plausible developmental answers to the question of adult creativity.

According to one theory, those people succeed to become creative in later life who have an early match between their talent and their field of activity. One has to be careful here because there is the phenomenon of "burnout." The crucial factor in addition to talent is curiosity in a field of activity. Where does curiosity come from?

The author John Briggs has suggested that lifelong curiosity results from early experiences of "nuance," waking up to a special kind of sensitivity to the universe. Einstein had such an incident in his childhood, as did the poet Rabindranath Tagore and the novelist Virginia Woolf. What is nuance? In the quantum-within-consciousness view, nuance is a partial experience of the quantum self, a glimpse at it, in which one wakes up to the creative purpose of the universe, which is for consciousness to see itself in manifestation.

Creative people are also those people who transform danger into opportunity, an evil cadaver into "something rich and strange," to quote Shakespeare. This is because in our quantum modality, even evil is not perceived as separate from us; thus, we can transform it.

Development theorists make good points, but the points they make are not necessar-

ily contradictory to the idea that anyone can be creative. Just as helpful traits can be learned on the job, the quantum self can be glimpsed at any age, and with that glimpse, all of us have the ability to wake up to our creative potential.

The Role of the Unconscious

The psychologists Sigmund Freud and Carl Jung both have emphasized the role of the unconscious as crucial to creativity. Freud believed that creative people put their childhood's repressed material to creative use. According to Freud, Mona Lisa's smile came from repressed childhood feelings of Leonardo da Vinci about his mother. Jung, on the other hand, saw creativity as a drive from the collective unconscious to make normally repressed, archetypal themes conscious.

In the quantum view, because of childhood trauma, certain states of the correlated brain-mind may very well be excluded from conscious collapse in later life. These states then contribute (via unconscious processing, of course) to fantasies and play, which all creative people use.

We can understand Jung's repressed archetypal themes in the same way. For example, males would tend to repress mental states that pertain to the experiences of a female body, for which they have no context. This is the origin of the repressed anima archetype. The repressed male archetype, animus, in females can be understood in the same way.

But ultimately, we are the whole, and we do have the capability of collapsing the mental states of all human individuals—past, present, and future. (An apt metaphor for this ability is the universal hologram.) Creativity liberates us from conditioned preferences and phobias, personal and collective.

Inner Creativity

Creativity researchers have begun to take notice of inner creativity only recently. In 1993, the *Creativity Research Journal* dedicated an entire issue to the subject of creativity in ethics. This is very welcome. However, as a culture, we still tend to exclude inner creativity unless we are in "spiritual" pursuits.

The quantum view of creativity developed here should help change our attitudes toward inner development, even as adults. As children we are all creative. Then we reach an adequate homeostatic condition in which we have a sufficient repertoire of learned contexts from which we carry out the jobs needed—for making a living, romancing a partner, being parents, etc. But the ego does not have to be the end of our journey in inner creativity. Self-development can continue beyond ego.

We have polarized the outer and the inner so much that an entire culture, the East, is identified with explorations of inner creativity, and similarly, the West is identified with explorations of outer creativity. But is this polarization necessary or welcome? I submit that continuing the journey of creative growth beyond ego through inner creativity enhances our potential for outer creativity. And conversely, engaging in outer creativity

gives us expressions of the inner, quantum self-explorations into the outer arena, enriching civilization.

The Process of Inner Creativity

The process of inner creativity is similar to the process of outer creativity, but there are also differences. Let's first explore these differences.

The ego presents two basic obstacles to our further developmental growth: conditioning and simple hierarchy. In outer creativity, we temporarily rise above these ego-tendencies in a chosen field, encounter the creative and tangled hierarchical quantum self, and then return to our ego-homeostasis. In inner creativity, we want to stabilize our self-identity beyond ego.

So we may begin with a self-discovery process: What is my pattern really? What defines my ego boundary? Meditation, watching our thought processes, is therefore a part and parcel of inner creativity in all of its stages.

Once we uncover the patterns of our conditioning, our limitations and boundaries, how do we deal with them? The spiritual traditions of the world have developed five different paths in the journey beyond ego, which are now being studied in the new force of psychology called transpersonal psychology. These five paths are the path of wisdom, the path of love, the path of right action, the path of the body, and the path of meditative ecstasy.

The *path of wisdom* is the closest in spirit to outer creativity because we attempt to discover new mental contexts beyond the repertoire of the ego, but they are contexts of living. We want to transform our being toward happier and happier living. We cannot do so by trying to live the contexts, true as they may be, discovered by other people. This is what exoteric religions preach–they tell us how to live but do not give us techniques. The preachers themselves are too cynical to practice any technique. But the mystical cores of all spiritual traditions are different; they fully appreciate the need for a creative approach to wisdom.

The *path of the body* is also similar to outer creativity, but now creativity of the body is emphasized. Like the mind, our bodies also settle down in conditioned homeostasis, but most of us in modern times do not identify with the body. Our ego-identity is almost entirely tied to our mind. So the strategy here is to shift our identity beyond our mental ego to a more general one that includes the body. The East Indian hatha yoga and the Oriental martial arts are examples.

In the *path of meditative ecstasy* (called *samadhi* in Sanskrit), meditation practices are used to transcend the ego. There are two kinds of meditation: concentration and awareness. In concentration meditation, we concentrate on an object of meditation, for example, a particular thought. We think the same thought, a mantra, over and over, silently in our minds. If other thoughts enter, as soon as we notice them we firmly return to our thought object. When the absorption with our object of concentration becomes total, the subject pole tends to fall away, and with it the object pole also. The result is *swavikalpa samadhi*–a realization that subject and object, although split, are not as separate as the ego makes them appear. Instead, the subject and object arise codependently.

In awareness meditation, we learn to become witnesses to whatever happens in our

awareness. Now we are focussing on the subject pole of awareness. When we become perfect witnesses, once again *samadhi* results. In *samadhi*, the ego is transcended. There is awareness, but it is pure awareness, the knower self, the known object, and the field of awareness all come together. The self in this experience is objective and universal, and the experience is full of spiritual ecstasy of the unlimitedness of consciousness.

The *path of love* has no parallel in outer creativity. However, it is still a path of inner creativity because it serves the objective of shifting our identity beyond ego. The path of (unconditional) love achieves its objective by practicing tangled hierarchy in relationship with other humans; the object is to undermine ego's simple hierarchy at its base. So we follow ethical rules to tune our behavior with others beyond our selfishness. The philosopher Immanuel Kant gave us the idea of ethics' being categorical imperative; but it is categorical imperative only to those who are committed to inner creativity. By practicing ethics, by practicing love, neither of which can truly be done within a simple hierarchy, we discover the "otherness" of others (as a result of a quantum leap of insight, of course), we become truly tangled hierarchical, and we fall into an identity beyond ego.

The *path of action* is similar to the path of love, only the emphasis is not on relationship, but on action itself. By pursuing right action, action that emanates from ethics, not from our desires, we discover that our egos are not the cause of our action. In this way we discover the true nature of consciousness.

Within each path, however, we still have to go through the four stages: preparation, unconscious processing, insight, and manifestation. We still have to engage in alternate striving and relaxation. The sudden insight is now given exotic names such as *satori* or *samadhi*, or seeing the inner light. Notice, however, that during manifestation, in outer creativity, we get ego-strengthening; in inner creativity, we get a weakening of the ego-identity. Ego functions remain, but they are not identified with.

Polarization and Integration

As already mentioned, the culture in the West is highly polarized in valuing outer creativity, whereas Eastern cultures still value inner creativity over outer. Is this polarization necessary? I would argue that the polarization is not only unnecessary, but also emphasizing both inner and outer creativity will help us actualize our creative potential in both arenas like never before.

No polarization is necessary because both inner and outer activities are parts of the play of consciousness to see itself, and both are important. When we don't value inner creativity, we get outer creative actions gone rampantly destructive without ethics to guide them. When we don't value outer creativity, the material structures of societies dwindle.

The truth is, the techniques of inner creativity can help outer creativity. Anyone who has meditated knows how it helps us to concentrate and to relax as necessary. Being aware of our bodies will make us more complete and healthy human beings. If we engage in outer creativity with love for humanity in mind, only good can come out of that. Similarly, if we learn to engage in acts of outer creativity with humility (we are not the doer) and without big ego postures, it will only be easier to make the creative quantum leap to new insights.

Likewise, we can look forward to the time when people of inner creative wisdom will engage in outer creativity, science, arts, music, etc. I submit that music, art, and science that are dedicated toward the whole and flow from the inspiration of wholeness–and not just from social-accomplishment orientation–will reach unprecedented levels of greatness.

What is the way to optimally educate our children toward creativity? It is to instill in them the idea that creativity–both inner and outer–is important, and it is a lifelong endeavor. In addition to teaching children how to labor and reason, let's also teach them the value of discontinuous insight and unconscious processing that precedes it. In addition to the three Rs (reading, 'riting, and 'rithmetic), let's also emphasize the three Is (insight, intuition, and inspiration).

Bibliography

Amabile, T. *The Social Psychology of Creativity*. NY: Springer-Verlag, 1983.
Barron, F. *Creative Person and Creative Process*. NY: Holt, Rinehart, Winston, 1969.
Briggs, J. *Fire in the Crucible*. LA: Tarcher, 1990.
Csikszentmihalyi, M. *Flow: The Psychology of Optimal Experience*. NY: Harper Collins, 1990.
Gardner, H. *Creating Minds*. NY: Basic, 1993.
Goswami, A. *Quantum Creativity*. Cresskill, NJ: Hampton Press, 1999.
Goswami, A. "The Quantum Theory of Creativity," In *Encyclopedia of Creativity*, M.A. Runco and S. A. Prizker (eds.), NY: Academic Press, 1999.
Gruber, H. *Darwin on Man*, 2nd ed. Chicago: University of Chicago Press, 1981.
May, R. *The Courage to Create*. NY: Bantam, 1976.
Piaget, J. *The Development of Thought: Equilibration of Cognitive Structures*. NY: Viking, 1977.
Searle, J. *The Re-Discovery of the Mind*. Cambridge, MA: The MIT Press, 1994.
Wallas, G. *The Art of Thought*. NY: Harcourt, Brace, and World, 1926.

CHAPTER 24

Integrating Dualities

A basic problem of philosophy is to establish monism underlying all the apparent dualisms that exist around and about us. Some of these dualisms are:

- Consciousness/Matter
- Transcendent/Immanent
- Unconscious/Conscious
- Subject/Object
- Life/Nonlife
- Mind/Brain
- Exteriority/Interioroity
- Subject/Person

The straightforward approach, of course, is to consider all of these as real dualities—this is the philosophy of dualism. However, the philosophy of dualism is not considered tenable if we take a scientific, explanatory, and verifiable approach. Take the dualism of consciousness and matter, for example. If consciousness and matter are truly dualistic, that is, made of two different substances, then how do they interact? Their interaction requires a mediator. The obvious absence of a mediator speaks in favor of monism.

According to many physicists, scientists, and philosophers, physics must be carried out on the basis of the philosophy of material or scientific realism—the philosophy that

A. Goswami, *The Physicists' View of Nature*
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only matter is real, and all else—including consciousness—is epiphenomenon of matter. It is assumed that such an approach serves to establish monism, a monism based on material supremacy, over dualism. But material monism is a pseudomonism. In truth, material realistic models of consciousness are unable to explain what the philosopher David Chalmers calls the hard questions of consciousness, such as the subject-object split nature of experience.

Similarly, there are holistic approaches within the basic materialist ontology that try to resolve the consciousness/matter and transcendent/immanent dualisms by regarding consciousness as a holistic aspect of matter (the whole is greater than the parts), but they completely ignore the transcendent aspect of consciousness.

The philosopher Daniel Dennet agrees that materialist cognitive science models of consciousness in the brain do succumb to an underlying dualism, the implicit idea that a homunculus is looking at the computer output that the brain generates. Dennet's own answer is operationalism (also called logical positivism). Consciousness is a purely operational concept. There is no substance to it and no causal efficacy, and thus no explanation is needed for the hard questions of consciousness. Operationalism does not work because consciousness does have causal efficacy, as exhibited in such phenomena as creativity, ethics, and spirituality.

The physicist Henry Stapp has shown that in classical physics, there are only two ways that consciousness can be treated. I have shown, and you are reading in this book, that if quantum physics is interpreted on the basis of the primacy of consciousness as according to the philosophy of monistic idealism, then all the well-known paradoxes of quantum physics can be resolved satisfactorily.

Like material realism, the philosophy of monistic idealism is very old. The oldest known version is probably the Indian Vedanta, but the esoteric traditions behind all great religions, for example, the Jewish Kabbala, are based on this philosophy. In the Western academe, Plato is perhaps the most easily identified monistic idealist.

In monistic idealism, consciousness is the ground of all being and is transcendent. What we see as the manifest reality lies transcendent within consciousness until consciousness creates it by a power that Easterners call *maya* and that Plato identified as projection. The transcendent and the immanent are complementary aspects of one and the same thing; *nama* (name) and *rupa* (form) in Vedanta, *yang* and *yin* in Taoism, Heaven and earth in Christianity, and the archetypes and the shadow show in the allegory of Plato's cave are examples of such complementary pairs. This pair, along with consciousness (which transcends them both), makes up the trinity common to all the great spiritual traditions.

Thus, in the monistic idealist philosophy of the Hindus, the subject-object split awareness that we experience is regarded as an appearance and is considered a result of *maya*, which is a discontinuous movement in consciousness for which no logical explanation can be given. Buddhists make this a little more clear with their doctrine of *patticha sammupada*, dependent coarising of subject and object, neither of which have self-nature apart from consciousness, which is the only being. (Outside of Hinduism and Buddhism and, in general, the Eastern religions, however, the cosmology—how the one consciousness, the ground of being becomes many—takes on a variety of forms, and the unity of all traditions is far from obvious.)

So in monistic idealism (of the East, at least), there is a symmetry between the subject

pole and the object pole of an experience (they both are appearances), whereas in material realism the object pole is considered real and the subject pole a mere epiphenomenon. What is more is that quantum physics supports and explicates the idealist cosmology of how manifestation comes about.

The traditional literature of monistic idealism is quite emphatic about the monism behind all dualities. However, it is silent about explicitly resolving such dualities as the mind-brain duality, the life-nonlife duality, and the interiority-exteriority (of awareness) duality.

The purpose of this chapter is to give elaboration when needed, and new explanations when called for, of all the dualities mentioned above using the idealist interpretation of quantum mechanics. Note that I am not saying that all dualisms are bad or contradictions, but only that if we are to take a scientific approach, we must incorporate the dualities on a monistic basis. Also note that the ideas in this chapter are often repetitions of ideas already discussed in previous chapters, but the repetition may be helpful for the sake of completeness.

Quantum Measurement Theory: Monism Behind Consciousness-Matter and Subject-Object Dualities

We will begin with another review of quantum measurement theory. In quantum physics, objects are depicted as waves of possibility or superpositions of possibilities. Quantum mathematics enables us to calculate the probabilities associated with each of the possibilities of a possibility wave.

But there is no quantum mathematics for calculating the reduction of the possibility wave to a unique actuality. Thus this collapse or reduction of the possibility wave to actuality must be regarded as a discontinuous movement of choice, complementing the continuous and deterministic movement in between measurements.

The mathematician John von Neumann argued that the choosing agent has to be a nonmaterial consciousness that transcends space, time, and quantum mechanics because any so-called measurement machine, being made of submicroscopic matter waves of possibility, is itself a wave of possibility. (The job of the "measurement" apparatus is not to "measure," which it cannot do, but to amplify the submicroscopic signal into a macroscopic one, which it can. Measurement apparatuses are really measuring aid apparatuses.)

But here is that dualism again: Can nonmaterial consciousness act on matter without an intermediary? The dualism disappears when we posit consciousness as the ground of being and matter as waves of possibility within consciousness. Notice that this agrees with our intuition that a possibility makes sense only when embedded within consciousness that considers it. Consciousness recognizes one of the possibilities, which is chosen and becomes the actual event. The paradox of Wigner's friend—Whose choice counts when there are conflicting possibilities and more than one observer choosing?—is resolved by the monistic idealist doctrine of one consciousness. There is always one consciousness choosing, and the choice of that one is free for which no mechanism or algorithm can be given. Our individuality and predictability arise from conditioning.

Conscious-Unconscious Distinction and Subject-Object Split

When is a measurement? In quantum mechanics, all phenomena are registered phenomena—registered in the brain of an observer. Collapse of the possibility wave occurs only when there is an observer looking with awareness. In the absence of collapse, no looking or sensory perception, there is consciousness, but there is no awareness. This is called *unconscious processing* in the literature.

In conscious processing there is awareness, there is a subject-object split. Quantum measurement involving the brain, because of its tangled hierarchical nature, creates the subject-object split.

In this way, quantum measurement theory clarifies the role of the discontinuous movement (collapse) that Easterners called *maya*. *Maya* is not explained, Easterners are right about its being beyond logic. But the tangled hierarchical nature of quantum collapse explains self-reference, the subject-object split of experience.

Finally, is there any evidence that consciousness is needed to collapse the quantum waves of possibility? There is—the experiment of Helmuth Schmidt, which is experimental metaphysics par excellence (see Chapter 22).

Life-Nonlife Duality

We do not need to be anthropomorphic, however, by insisting that a human observer with a brain is needed for quantum collapse. Instead, here we have a wonderful opportunity to distinguish life from non-life.

What is life? The biologist Humberto Maturana has correctly pointed out that what distinguishes life from non-life is subject-object cognition—the ability to see itself separate from its environment. How does this ability arise? We posit that a self-referential (that is, tangled hierarchical) quantum measurement takes place in a living cell producing the ability to distinguish itself from its environment. This way of viewing life has led to an understanding of biological evolution as a punctuated equilibrium (see Chapter 29).

The Mind-Brain Problem: A New Psychophysical Parallelism

In Western psychology consciousness and mind are not distinguished. Moreover, the current prejudice of cognitive science is that mind is brain. In monistic idealist psychology, however, mind and brain are recognized as two distinguished bodies of consciousness (the brain is part of the physical body, of course).

Why do we need a mind separate from the brain? As mentioned before, computer scientists are gradually conceding that brain, looked upon as a computer, a symbol processing machine, cannot process meaning. Suppose we reserve some of the symbols for processing meaning. Then we will need more symbols to process the meaning of the meaning symbols, and still more symbols to process the meaning of the meaning of the meaning symbols, *ad infinitum*.

So the mind is needed to process meaning. The mind gives meaning to the symbols of the physical world, as is clear in such actions as watching TV. At the physical level, the movements on the TV screen are electronic movements, but physics does not tell us about the meaning, as the Nobel laureate biologist Roger Sperry used to emphasize.

But if mind and brain are disparate bodies made of different substances, then, the specter of dualism raises its ugly head again. What mediates the interaction of mind and brain?

In a quantum-within-consciousness model of reality, there is an answer to this dualism also. To see the answer, consider once again the experiment carried out by the neurophysiologist Jacobo Grinberg-Zylberbaum and his collaborators.

Two subjects meditate together for twenty minutes with the intention of direct (nonlocal) communication between them, which they maintain for the rest of the duration of the experiment. Then they are separated in electromagnetically isolated chambers, and their brains are connected to individual electroencephalogram (EEG) machines. One subject is shown a series of light flashes producing a well-known electrical response in his brain, recorded as an "evoked" potential in the EEG. Surprisingly, the partner, who does not see light flashes and who does not even know the exact time of the light flashes, also registers electrical activity in his or her brain recorded by the EEG as a "transferred" potential, similar in strength and phase to the evoked potential. (Control subjects do not show any such transferred potentials.)

How did such a nonlocal transfer of a specific electrical activity in the brain occur? The succinct explanation is this: consciousness collapses (nearly) identical actualities in the locally isolated but correlated brains from the possibilities available in both brains. This gives rise to the idea that consciousness can nonlocally mediate the interaction of the brain and mind provided, like the brain, the mind also consists of quantum possibilities within consciousness.

The reader will recognize that this solution is similar to the old philosophy of psychophysical parallelism enunciated by the great Gottfried Leibnitz—brain and mind function parallelly in exact correspondence. However, in the old philosophy, there is a subtle dualism—what maintains the parallelism? With quantum collapse of correlated brain and mind, consciousness maintains the parallelism.

We now can see the full analogy with the computer. Brain gives symbols, it is the hardware. Consciousness (the programmer) uses the mind to give correlated meanings to the symbols of the brain, creating software.

Is there any evidence that mental movements of meaning are quantum movements? The telltale signs of the quantum movement are discontinuity and nonlocality. The discontinuous movement of the mind is apparent in creative acts, which can be regarded as a discontinuous shift in meaning. The nonlocality of mental movement is also well known—it is called telepathy. Mental telepathy has been verified in the laboratory by many experiments.

In one kind of experiment, called distant viewing, one psychic looks at a public spectacle such as a waterfall, and another psychic draws a picture of what is being viewed from a distance, without local signals and without prior knowledge of where the viewing psychic would be. The match between the object and the drawing is done by a computer, and the results are often astounding.

Exteriority and Interiority of Awareness

One of the deep puzzles of awareness is why the physical world is experienced as external, public, and objective, but the mental is experienced as internal, private, and subjective. The explanation lies in how the uncertainty principle plays in the mental world as opposed to the physical world.

First, let's discuss in what way the movements of the modes of the mind obey a quantum uncertainty principle. As the physicist David Bohm pointed out, the movement of meaning is collapsed in thought in two very distinct and complementary manners that suggest the play of the uncertainty principle. When we keep track of the meaning (the feature) of every thought, we lose track of the direction (the association) of thought. And when we center on the direction of thought, we lose track of individual meanings. Thus, feature and association of thought are two complementary aspects of the movement of meaning akin to the position and velocity of material objects. For material objects, both the position and velocity can never be ascertained simultaneously with complete accuracy—this is the uncertainty principle. Likewise, for meaning objects of the mind, both feature and association can never be ascertained simultaneously with complete accuracy. The uncertainty principle plays a big role in the mind's being experienced as internal.

Let's examine the situation with how we experience the physical world. The physical, as Descartes recognized, is *res extensa*, body with extension, and, therefore, divisible. In other words, in the physical world, microbodies make up macrobodies.

In contrast to microbodies of the physical world, for whom the uncertainty principle is a dominant influence, for macrobodies of large mass and size, the uncertainty principle becomes relatively ineffective. What that means is that the possibility waves of the macrobodies are very sluggish in their expansion between measurements. So what I observe of a macrobody is what you observe a little later; our observations thus form a consensus, because in between the two observations the quantum uncertainty of the macrobodies is very small. Another way of seeing this is that because of the subdued action of the uncertainty principle, our observation does not affect the macrobodies in any appreciable way.

The physical world is also built in such a way that we never directly see the micro; we see the micro with the intermediary of the macro. The macroscopic measurement apparatuses we use to "see" the micro amplify the micro, giving us some kind of a reading of a macroscopic pointer. Since the pointer is macroscopic, once its possibility wave is collapsed as a result of a quantum measurement by a conscious observer, it expands rather slowly in possibility. So another observer is going to the see the pointer essentially giving the same reading, giving rise to a consensus. It is this sharability of observations giving rise to consensus that creates the illusion that our physical reality is objective, independent of the subject, that it must be external to us.

Now compare the situation with the mental world. As Descartes correctly realized, the mind is indivisible, like what physicists call an infinite medium. Thoughts are meaning waves of this infinite medium.

Thus mind is indivisible. There is no micro-macro division. The advantage of this is that we can directly think thoughts, quantum as they are, very susceptible to quantum uncertainty. There is no intermediary we need to use. The disadvantage is that the possi-

bility waves of meaning spread fast between two observations, the uncertainty principle demands that one observation (thinking) affects the thought so much that nobody else can think the same thought (unless in special situations of nonlocal correlation, as in telepathy). Therefore, thoughts are not normally shareable; we experience them as private, and therefore as internal.

The truth is, then, that both the physical and the mental worlds are internal to consciousness, but because of the different ways the two worlds are built, the physical is experienced as public and external, and the mental as private and internal.

Subject-Person Duality

Although many of us report occasionally having spontaneous experiences of a nonlocal and universal self, most often we experience ourselves as a "person," individualized and identified with a seemingly local body-mind. This raises another duality. Do we have two "I"s, one nonlocal and universal, and the other local and personal?

The subject of the subject-object split in quantum measurement is universal and nonlocal, and is experienced as such. I call it the quantum-self experience. The quantum, universal, nonlocal self is akin to the ***atman*** of Indian philosophy called Vedanta and the Holy Spirit in Christianity. But how does the ego arise?

The ego arises because of our tendency to process sensory data via the reflection in the mirror of past memory before we experience them. A part and parcel of quantum measurement in the brain is the formation of memory. If a previously experienced stimulus arrives at the brain, not only is there a primary awareness experience connected with the direct perception of the stimulus, but also a series of secondary awareness experiences. This is because the brain plays back the memory, which now acts as a secondary stimulus. However, if there are both a primary stimulus and a secondary stimulus, the quantum response of the brain is found to be biased, the probabilities are more favorable for the previous response. Thus, with increasing reflection from the mirror of past memory we acquire conditioning, a habit pattern, a character, which is clearly identified with a person. Apart from the personal history carried in our memories, this character is the main ingredient of our persona, our individuality.

Since the mind and brain are correlated, parallelly acting bodies, the mind also acquires conditioning in this way in the process of making "software" representation of the mind onto our brain. We thus acquire a mental character, a mental pattern of propensities.

The mind does not have micro-macro division. There is no structure in the mental world; we all share the same mind. However, as we acquire a mental character, we tend to use some mental functions more than others. This gives us functional identity that we call the individual mind. It is the individual mind that is the basic ego-identity. Apart from our structural body identities, there is nothing more important to us than these individualized mind-identities. We identify with our individualized minds so much that we tend to experience them as rigid structures. This is the ego.

Notice that there is no duality in this explanation of the quantum self and the ego because both selves are clearly recognized as mere identities of one consciousness. The quantum self is an identity arising from the (false) identification with the subject-pole of

the subject-object split experience. The ego identity is an identity arising from identifying with the conditioned and limited functional mind.

Conclusions

I have shown that if physics, and science in general, is carried out within the primacy of consciousness, then the dualities that commonly frustrate philosophy are resolved. We cannot do this so long as we use classical Newtonian physics. But quantum physics has opened the door toward this science-within-consciousness that is duality-free. The conclusion, then, is straightforward. All science needs to be extended using this quantum-within-consciousness interpretation of quantum measurement. This new science-within-consciousness goes smoothly into the conventional, classical-physics-based materialist science in the limit of complete conditioning. This is the correspondence principle. The existence of such a correspondence principle reassures us that we have a genuine paradigm shift in our hands.

Bibliography

Banerji, R.B. *Beyond Words.* Philadelphia: St. Joseph's University, 1994. This is one computer scientist who has proven that computers cannot process meaning.

Chalmers, D. *Toward a Theory of Consciousness.* Cambridge, MA: MIT Press, 1995.

Dennett, D. *Consciousness Explained.* NY: Basic, 1991.

Eccles, J.C. *How the Self Creates Its Brain.* NY: Springer-Verlag, 1994.

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World.* NY: Putnam/Tarcher, 1993.

Goswami, A. *Quantum Creativity.* Cresskill, NJ: Hampton Press, 1999.

Grinberg-Zylberbaum, J., Delaflor, M., Attie, L., and Goswami, A. "Einstein-Podolsky-Rosen Paradox in the Human Brain: The Transferred Potential." *Physics Essays*, vol. 7, 422-428, 1994.

Herbert, N. *Elemental Mind.* NY: Dutton, 1993.

Jahn, R. "The Persistent Paradox of Psychic Phenomena: An Engineering Perspective." *Proceedings of IEEE*, vol. 70, pp. 135-170, 1982. A good original source of a successful experimental study of telepathy.

Maturana, H. "Biology of Cognition," in Maturana, H., and Varela, F., *Autopoiesis and Cognition.* Dordrecht, Holland: D. Reidel, 1980.

Penrose, R. *The Emperor's New Mind.* Oxford: Oxford University Press, 1989. The limitation of artificial intelligence research is exposed.

CHAPTER 25

Quantum Cosmology and Consciousness

The universe is creative but its creativity is camouflaged. The external world of our experience seems deterministic to a large extent. Bodies at large have huge, macroscopic masses, and as wave packets, they spread so slowly that we tend to see them as moving in predictable trajectories. Only very recently, with laser measurement, have we been able to verify that even macro objects are subject to Heisenberg's uncertainty principle, that their wave packets do spread. For an average macro object, the observed spreading is only 10^{-17} m per sec. or so, but that does put the illusion of classicality in its place. This and the measurement in connection with superconducting quantum interference devices discussed in Chapter 15 convince us that all of the world of matter belongs to quantum dynamics.

Even so, space and time, it seems, are not quantized. Space and time seem to be infinitely divisible. So is the universe in the bulk classical, hence determined? No, say the physicist Steven Hawking and others, who have put forth the idea of a quantum early universe. Their work is theoretical, but highly appropriate.

Before the advent of quantum cosmology, the universe was theorized to have been created in a big bang, an explosion of cosmic proportions, which would explain the observed expansion of the universe. The truth is, galaxies recede from one another; the universe is like a spherical rising raisin bread (see Chapter 17 of Volume I), with galaxies akin to the raisins. The separation of the raisins increases as the dough of the bread expands. Similarly, the galaxies move further and further away from one another as space expands between them. Empirical proof of the expanding universe is found in the measurement of

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the recession of galaxies. Light from receding galaxies is found to shift in frequency toward the red in accordance with what we expect by virtue of the so-called Doppler effect (see Chapter 11, Volume 1). Empirical proof of the big bang is the microwave background radiation that bathes us from all around and is therefore of cosmic origin. Calculations demonstrate that the frequency of the microwave background is almost exactly as predicted from a big bang origin of the universal expansion.

So far so good. But there is a problem. Here is a story about St. Augustine. Augustine was teaching one day about creation—on how God created Heaven and earth. One fellow in the back retorted, "Hey, Augustine, you always tell us about how God created Heaven and earth. But what was God doing before He created Heaven and earth?" Augustine was confounded momentarily, but recovered nicely. "God was creating Hell for people like you who ask such questions!" he quipped back.

But the student's question was a good one. If there was a finite moment of creation, we can always ask, what was before the creation—before the big bang?

There is more sophisticated way of pondering the issue. According to the theory of general relativity underlying the big bang cosmology, the point of cosmic origin is a mathematical singularity when the density of the universe was infinitely great. But this also means trouble—our theory, general relativity itself, breaks down near the point of the singularity. Some other theory must take the place of general relativity in those early times.

Hawking and others have suggested that the early cosmos was a quantum cosmos—the universe is a quantum wave function, a superposition of many baby universes of possibility. The assumption of a quantum cosmos solves the issue of beginning. There is no beginning; there is only possibility, always. The important question now is, How does possibility become actuality? The universe of possibilities exists in transcendent potentia; how does it manifest and become immanent physical reality?

Self-Reference and the Origin of Life

For the idealist interpretation of quantum mechanics, measurement involves conscious observation. Transcendent consciousness collapses the wave function of the universe from outside space and time.

One may object. Consciousness and its possibilities manifest through us, sentient beings that take time to evolve. How can consciousness observe when there is nobody around? This is a valid objection. But the misunderstanding is to think that evolution takes place only in manifest reality. Instead, realize that the universe evolves in potentia, as a superposition of possibilities, until a sentient being comes about in one of the possibility branches. Then the circuit is complete and self-referential quantum measurement collapses a subject-object experience. Actually, this solves a knotty problem of evolution involving small probabilities in some of the stages of cosmic evolution, such as the evolution of life.

Theories of the evolution of life have a long history. At one point Eugene Wigner claimed to show that evolution of life (defined as a self-replicating entity) from nonlife is impossible. Later, it was found that one of Wigner's assumptions was too restrictive. When

corrected, it was found that there is a probability for self-replicating life after all. Unfortunately, the probability for life evolving from nonliving matter, though finite, is extremely small. (And of course, if we define life as capable of subject-object cognition, we are back to square one. Even a small probability is then denied for the evolution of life from nonlife.)

But if the universe is manifest only when consciousness self-referentially observes itself through the senses of the first sentient being, the argument of small probability is no deterrence. It is a unique event of free will and creativity. The act of cosmic creation happens after much unconscious processing, and probability considerations do not apply.

Unfortunately, it is hard to believe that the universe waits in potentia until a sentient being in one of its possibility branches on a measly little planet evolves and observes. Also, what about all the evidence of a big bang some fifteen billion years ago, for which the microwave fossil radiation carries the time signature? Fortunately, there is an experiment that resolves our confusion; it's called the delayed-choice experiment.

The Delayed-Choice Experiment

Nowhere is the importance of conscious choice in the shaping of quantum reality better demonstrated than in the delayed-choice experiment first suggested by physicist John Wheeler (Figure 25.1). It is a variation on the previously discussed double-slit experiment, but with a new twist. As in the double-slit experiment, we split a light beam into two beams of equal intensity, but instead of using two slits for the purpose, we use a half-silvered mirror, M_1. The two beams of light are then reflected by two regular mirrors, A and B, to a crossing point, P, on the right (consult the figure). If we choose to detect the particle mode of the photon, we put detectors or counters past the point of crossing P, as shown in the lower left in Figure 25.1. One or the other counter will detect the photon, defining its localized path, showing its particle aspect.

To detect the wave aspect of the quantum of light, we take advantage of the phenomenon of wave interference. If we put a second half-silvered mirror, M_2, at P (Figure 25.1, bottom right), the two waves created by the beam's splitting at M_1 will be forced by M_2 to interfere constructively on one side of P (where the counter activates) and destructively on the other side (so the counter on this side never ticks). But notice that when we are detecting the wave mode of the photons, each photon must be traveling by both routes A and B—otherwise how can there be interference?

But there is even subtler aspect of the experiment, and this is where it is different from the double-slit experiment. In the delayed-choice experiment, the experimenter decides at the very last moment, in the very last 10^{-10} second or so (during the time interval it takes for light to travel from M_1 to P), whether or not to insert the half-silvered mirror at P, whether or not to measure the wave aspect. In effect, this means that the photons have already done their travel past the point of splitting at M_1! Even so, inserting the mirror at P always shows the wave aspect, and not inserting the mirror, the particle aspect. Was each photon moving in one path or both? The photons seem to respond to even our delayed choice instantly and retroactively! A photon travels one path or both paths, ex-

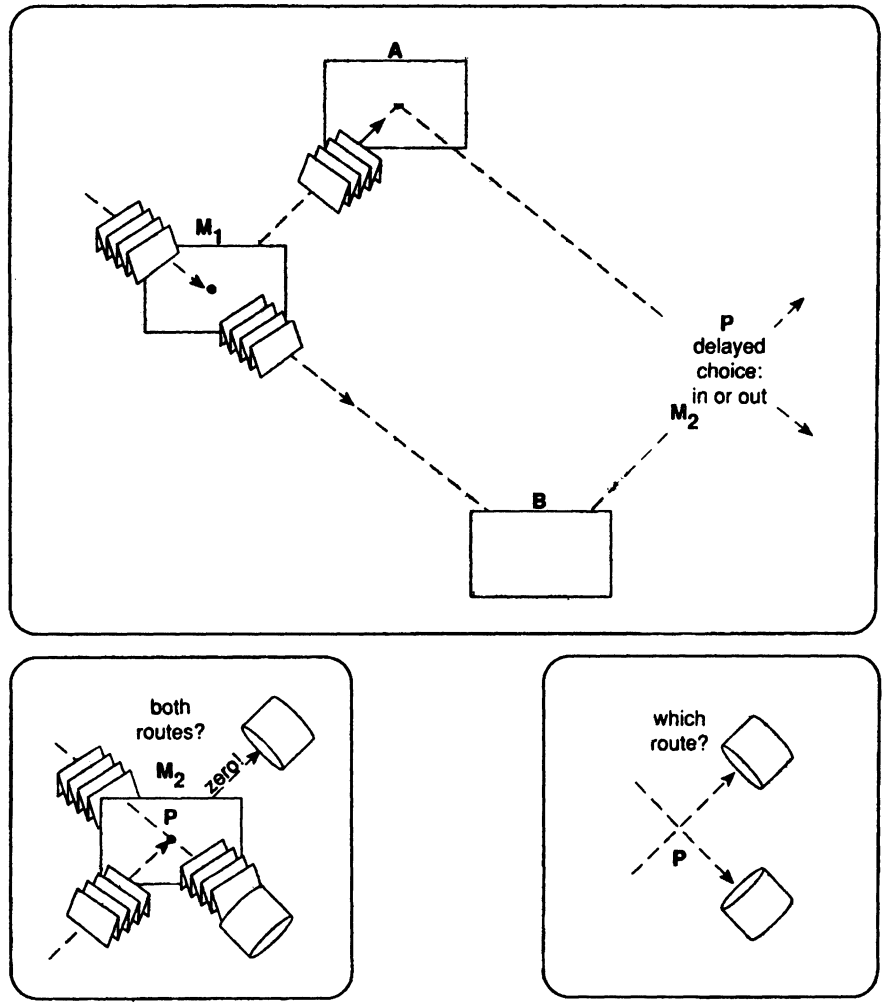

Figure 25.1
The delayed-choice experiment. Bottom left—the arrangement for seeing the wave nature of photons. One of the detectors never detects any photons, signifying cancellation due to wave interference. The photon must have split and traveled both routes at the same time. Bottom right—the arrangement for seeing the particle nature of photons. Both detectors click, although only one at a time, signifying which route the photon takes.

actly in harmony with our choice. This is a big puzzle if you think classically, if you think of photons as things. But in quantum thinking, we realize that there is no manifest photon until we see it.

You may have heard the story of the three baseball umpires who are talking about how they call the game. One of them says, "I call it like it is." The second one is a little less egotistic. "I call it like I see it," he declares. The third one is a quantum umpire at heart. "There ain't nothing until I call it," he says. And it is the same even if the object is the entire cosmos. There is no manifest cosmos—only possibilities—until a sentient being calls the game and observes the universe.

The delayed-choice experiment has been verified in the laboratory, where the delay time was a few nanoseconds (billionths of a second). In principle at least, the experiment can be carried out in cosmic scale too, as suggested by Wheeler himself.

Cosmic Delayed-Choice Experiment

There are distant, bright, and compact objects in the sky called quasars—quasi-stellar radio sources—which are sometimes observed in duplicate. Surely, cosmic objects could not be created as identical twins, so there must be some sort of a mechanical duplication, but how does the duplication take place? The answer is that we are seeing one quasar, as well as its image formed by the gravitational lens of an intervening galaxy. Gravity bends light, as in refraction by a lens. (Einstein predicted this long ago, a prediction that has been verified with earth-based observations.) Now, the intervening galaxy can bend the light either right or left creating two pathways as in the experiment in the previous section. Of course, in this case bringing the two beams together at a point P to create the interference situation of the last section will not be easy, since in general the distance traversed by light in the two paths would be widely different. But, in principle, if we have the technology of moving about in space, we could always find the point P at which to put our second half mirror (or not).

But now, from the vantage point of P, the arms of the apparatus are billions of light years (the average length of a quasar) long. And so the delay time, likewise, is billions of years. Considering that the universe is no older than fifteen billion years, this is a considerable fraction of the age of the universe. Through such cosmic delayed-choice experiments, we can and do affect what we suppose has gone before, even long before, because only we—consciousness—can collapse a quantum dichotomy to uniqueness.

The Strong Anthropic Principle

So, to summarize, there is that circuitous, tangled hierarchical relationship again: we are here because of the universe, and the universe is here because of us. This last idea has become popular for some time and is called the strong anthropic principle.

Modern science began with Copernicus, whose model of earth revolving around the sun is something of an anti-anthropic principle. It robbed us, correct though it may be, of the Aristotelian notion of earth's, and with that our, being the geographical center of the universe. It became worse when it was discovered that even our sun is not the center of our galaxy, but resides at an edge. It became still worse with the discovery of cosmic expansion—every point of the universe is the center from which every other point recedes! But now we are back again in the total picture, not as the geographical center of the universe, but as its meaning center.

The strong anthropic principle is not mere philosophy. It explains a whole lot of coincidences, for example, why the universe is so fine-tuned in such very different ways. If the force constant of gravity or the charge of the electron were even slightly different from what they actually are, or if a nuclear reaction of three helium nuclei fusing to form the nucleus of carbon were not amplified because of a resonance (the same process that

has the potential to destroy a bridge if soldiers march on it in unison with a frequency that matches one of the natural frequency of vibration of the bridge), the universe would not have produced sentient beings, and in its turn would never be manifest in their experience.

Some physicists feel uneasy, even apologetic, for the anthropic principle. To them, it seems to be a thorn in the side of material realism because it violates the principle of strong objectivity that they so covet. But the quantum connoisseur knows that the objectivity of the universe at the macro level is a grand camouflage. The quantum idealist knows that the universe is the playground of consciousness, and manifest self-reference is the beginning of the play of consciousness.

The Arrow of Time

Quantum physics interpreted the idealist, consciousness-based way also solves a very difficult problem of physics called the problem of the arrow of time. The arrow of time invokes the idea of time's being a one-way street, inexorably, always proceeding from the past through the present into the future. But the laws of physics, Schrödinger's equation (or even Newton's classical equation of motion) is invariant under the reversal of the direction of time; they do not change if time runs backward. In other words, physical laws allow things to go both forward and backward in time, just as in movements in spatial directions!

So physical laws, the algorithmic part of physics, seem to have no explanation for the arrow of time. How does our experience of the arrow of time arise, then? Some physicists try to explain the arrow of time from the expansion of the universe: with the progress of time, the galaxies separate further and further, creating an arrow of time. But if the expanding universe creates the arrow of time, then does time's arrow reverse when the universe enters a contracting phase in which galaxies converge? Are we then born in our graves, and die in our mother's womb? Somehow, we intuit that it is not that way!

Quantum collapse has the answer for this quandary, as was pointed out by the great scientist Leo Szilard long ago. The mathematical equation of quantum mechanics, Schrödinger's equation, behaves the same whether you use it in the forward direction in time, or drive it backwards. This means that as far as the time evolution of the waves of possibility is concerned, there is no distinction between the past and the future. But quantum collapse of possibility waves to actual events has no such compunction. Collapse is discontinuous; for it, no mathematics, no algorithm can be given. Thus collapse can and does produce a time asymmetry—collapse creates the arrow of time because it is irreversible, so said Szilard.

In the idealist interpretation, there is no objective world out there. The world is what we experience in our awareness moment to moment, collapse by collapse. The objectivity of the macro world, the reason we perceive it outside of us, is due to the sluggishness of the quantum movement of the macro because of the huge masses involved. So between your observation and my observation, the environment changes little, creating the notion that we are experiencing the same environment. This consensus we mistake for reality's being independent of us, being objective, being public, being out there permanently.

The arrow of time, then, is ultimately subjective, arising entirely because we create time as a one-way street from the irreversibility of quantum collapse, with which we create the world in our experience.

Bibliography

Goswami A. *The Self-Aware Universe*. NY: Putnam/Tarcher, 1993. A good discussion of irreversibility and the arrow of time is available here.

Goswami A. *The Visionary Window*. Wheaton, IL: Theosophical Publishing House, 2000. A more complete description of idealist cosmology is given here.

Wyller, A. *The Creating Consciousness*. Denver, CO: Divine, 1996.

Part SIX

QUANTUM BIOLOGY—

HOW CONSCIOUSNESS CREATES BIOLOGICAL ORDER

CHAPTER 26

Anomalies in Biology and the Need for a Paradigm Shift

A whole delegation of people is here to see me. What a surprise! Four men and two women—they all look so much like establishment scientists. This is a group that usually avoids me and *moi* ditto. And yet, here they are—they have come to me because they probably need me to do something.

They are biologists, they tell me. "But I am a physicist, I know little about biology," I say to them.

"You have developed a way to bring consciousness within science. You have done it for physics, and you have done it for psychology. We would like you to bring consciousness also to biology."

I must be dreaming, I realize. Only in a dream would a bunch of establishment biologists come to see an idealist physicist like me—a physicist who bases physics on the idea of the primacy of consciousness. They confirm my suspicion.

"Yes, we are dream biologists, but hear us out anyway," they insist. "The current paradigm of biology has reached the crossroads. If it continues in its materialist way, if it continues to assert that life is nothing but a dance of atoms and our body-mind is a machine, then biology, the science of life, will soon reach a dead end. Biology needs a change of path, or else..."

"Or else it will be pathological for biology, eh?" I interrupt. "You want a paradigm

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shift. But paradigm shifts are not exactly a dime a dozen, you know. You have to pay the price. The initiation cost of a new paradigm is the demonstration of a whole bunch of anomalies in the old paradigm. Also paradoxes. Are you willing to demonstrate?"

"We are more than willing. We are ready," the biologists declare in unison. They confer among themselves for a bit.

"Okay, I will go first." A guy with a T-shirt marked with the words "life is chemistry" says. Originally, when I saw his insignia, I thought it meant that life becomes interesting when you have good chemistry with the environment. But now I am not sure. I don't have to wait in suspense much longer. "As you can guess from the slogan on my T-shirt, I have believed throughout my professional life that life has a chemical origin—it is nothing but an emergent epiphenomenon of the chemistry of molecules. When an assembly of certain chemicals reaches a certain threshold of complexity, wham-o! It is alive. It can self-organize, it can self-maintain, and it can self-reproduce. But now I am not so certain."

He seems ready to succumb to melancholy. I try to console him. "That idea of emergence seems like a worthwhile hypothesis for scientific study, right or wrong. Surely, that kind of hypothesis generates a lot of grant money and a whole bunch of publications. Isn't that the goal of establishment science?"

"When I was young, research grants and publications were enough and did satisfy me," the guy says sadly. "But now they don't satisfy. Also, now that I am older and established, I am a little less reluctant to admit my ignorance. Look, the fact is, I really don't know what life is. And I don't know anybody in the biological establishment who does."

"You are worried about the meaning of life like most mid-life transitioners are!" I cry. "Perhaps you ought to look up a mystic, a spiritual teacher, to be sure. I just do research on consciousness. I am a theorist, not a teacher of the meaning of life."

"I am not talking about the meaning of my life, but of life itself. What makes a single-cell creature alive? Clearly, it has established an integrity in its relationship to its environment, an integrity it preserves until it dies. It has a self as opposed to its environment. But how does it get its self?"

"Got you. If everything is made up of one level of things, atoms, matter, then we can never have a separation such as the living self and the non-living environment. Sure you can talk about molecules and atoms as hierarchies, but molecules don't manipulate atoms. They form a simple hierarchy. Ultimately molecules are nothing but atoms, completely determined by atomic interactions. But you suspect that the self-organization, self-maintenance, and self-reproduction that life represents manipulates the environment for itself. It has causal efficacy."

The chemist replies, "So there is your first paradox—life, if it is pure chemistry, having causal efficacy. Explain the causal efficacy of life with your idealist science based on the primacy of consciousness. We need you."

I am pleased. Indeed, causal efficacy is a good paradox, and right smack in the arena for consciousness to resolve. But I try to sound nonchalant. "That's just one paradox, important though it is. That may or may not be enough to pay for a new paradigm. What else have you got?"

The woman comes forth. As I turn my attention on her, I see that she has a small button on the lapel of her lab-coat that says "neo-Darwinism." The letters are so small that it is clear to me that she is not particularly proud of that identity.

"The biochemists and molecular biologists have had great success in explaining cell biology ever since the structure of DNA (deoxyribonucleic acid) was deciphered, and this makes them complacent. But a cell exists in a stasis of sorts. It does not represent the whole picture of biology. When we look at the problem of evolution, the complacency disappears.

"The neo-Darwinist compromise of all the post-Darwin developments on the evolution of species is falling apart. The anomalies are numerous. Neo-Darwinism, as you know, holds evolution to be an interplay of gradual, chance accumulation of genetic changes and the necessity of the survival of the fittest. But if evolution is so gradual, what caused the big spurt in evolution around the Cambrian era some 600 million years ago?"

"What indeed?" I am impressed. "So you think consciousness did it. Whose consciousness?"

"Well, it has to be more subtle than anybody's consciousness. Obviously, it is not a member of a species' desiring to evolve that brings evolution about. Anyway, you don't expect me to answer that, do you? You are the connoisseur of consciousness, not me. But you see, I do know something about evolution, and it is not only gradual. If evolution were written as prose, there would be punctuation marks all over it: commas, periods. How can evolution be gradual and also be occasionally rapid? The plot thickens when we realize that the two elements of the neo-Darwinian synthesis operate in two different arenas. The chance mutations, the genetic changes, are changes at the micro level of the organization. But the survival of the fittest—natural selection (it is nature that selects the superior, you know)—occurs at the macro level. So what is the connection between micro and macro evolution? We cannot seem to answer that within our materialist-machine models." She is a little out of breath.

I would never have guessed that there are such astounding anomalies in biology, especially in evolution theory. Those guys always seem so sanguine when they debate the creationists—people who believe all species to have been created by God in one fell swoop as laid out in the Book of Genesis. When I voiced my thought, my responder is candid.

"Yes, the creationists make it very difficult to publicly debate the difficulties and inadequacies of neo-Darwinism. Many biologists are still paranoid about admitting anomalies in neo-Darwinism lest they give ammunition to the creationist. Obviously, we cannot battle one dogma with another. Creationism is not scientific, of course. It is neither verifiable nor falsifiable. But neo-Darwinism falls short also. The funny thing is, the sudden spurts in evolution may be aspects of creativity, and neo-Darwinism is helpless to explain them because it holds on to one mechanism of gradualism. We need a shift in our thinking about evolution."

"And shift you will have, dear lady," I declare in an expansive mood. "What else? Any more anomalies?" I have an infinite appetite for hearing about anomalies of materialist thinking.

A tall man answers my plea. "I have to say something in support of my neo-Darwinist friend here. You know creationism is not scientific, but there are scientists among creationists. They cannot make creationism into a science, but they do point out legitimate faults in neo-Darwinist thinking. Take the case of entropy and evolution, for example."

The mention of entropy piques my interest immediately. There's a concept that as a physicist I can relate to.

The man continues. "Creationists make the valid point that there is something that does not jibe with the idea of evolution of complexity—complex creatures from simple one-celled beings—when looked upon from the point of view of the entropy law. Evolution of complexity from simplicity, of more order from little order, is a decrease of entropy. Entropy cannot decrease without the infusion of energy into the system. The chance and necessity of neo-Darwinism has no allowance for this. So in that theory, evolution should go both ways and there would be no biological arrow of time pointing to complexity."

I ponder. I always bought into the idea that life can evolve in the direction of decreasing entropy because entropy increases elsewhere, in the environment. But that may not be enough of an argument.

A fellow with a ponytail breaks into my thought. "Perhaps the greatest mystery, nay, anomaly, is morphogenesis—how a fertilized egg develop into a full-blown form. We now know that there are regulator genes that regulate the timing of various gene functions, but how do they operate across space and time? I have heard that in your quantum theory of consciousness you use the concept of nonlocal relationship. Obviously biological morphogenesis must involve nonlocal relationship—relationship between objects across space and time without local signals mediating their interaction."

"Hmmm," I feel excited. Nonlocality—action at a distance and across time—can never be simulated by deterministic machines. This is a very good sign.

The ponytailed fellow continues. "Then there are the patterns of morphogenesis—why biological forms exhibit so very few patterns. If evolution is random, why do only a few patterns repeat, and repeat with a purposiveness? This would not be surprising if there was a law of behavior operating, as in physics. But the repetition is not law-like. It is not exact replication—there are variations, as in memory recall. But who or what is memorizing, and where?"

"So you think somehow consciousness is involved, eh? Could be, could be." I am shaking my head in agreement.

The ponytail continues. "It has become fashionable to talk about programs in biology. Biological forms are the consequences of programmed behavior, as in a computer, we are told. But I wonder. If there are programs, where is the programmer? And don't tell me it is self-referential programming—the system's writing its own program. Don't tell me it is autopoiesis—the system's writing its own poetry. Nothing can emerge in a material system that has causal efficacy or purposiveness."

"He is right." The neo-Darwinist woman joins in. "Any open-minded evolutionist can see that there is purposiveness in morphogenesis and evolution. It is as if somebody knows what she wants to build, such as a creative sculptor, and builds it whenever the situation is right. And natural selection is just a stamp of approval. People either approve a creator's creation or they don't. Sometimes they approve long after the creation. And we do find instances of all of that in natural selection."

"So whose purpose is it, if not consciousness'? Who is the creator if not the power of manifestation of consciousness?" I am absorbed in thought, wondering if that power of consciousness manifesting in biological system is what we call *life*.

A guy with a British accent breaks into my contemplation. "Then there is the anomaly of ecology—the relationship of an organism and its environment defies materialist, deter-

minist, reductionist thinking. It requires us to generalize our study of the organism to include the environment, whereas the tendency of establishment biology is to reduce the problem in the opposite direction. I personally think that the whole earth and everything on it is a living system. I call it Gaia. But it would be nice to get philosophical support for Gaia from the science based on consciousness."

"Yes, of course. Do you think consciousness acts as Gaia?" I ask.

"I don't know what to think. My training is materialistic, you see. It is very hard to overcome my own prejudices."

This is a great, honest bunch of scientists, interested in truth. They are what we dream scientists should be like. How can I refuse them what they want from me? But there is one more person left. Is she going to say something? As if following my thought, the sixth and final person, a woman, speaks up.

"I can feed more fodder to anti-Darwinism by pointing out some data that supports Lamarckism—you know, the idea that environment contributes to evolution. There is a phenomenon called directed mutation in which a species, when proffered food that it cannot digest, but that a related species removed from it by a single step of mutated gene can, accelerates its own mutation rate and finds a way to survive."

That is very interesting. I can also see the importance of consciousness in that phenomenon. Darwinian objective mutation rates are fixed. If a species' consciousness can direct mutation, it must have the power of downward causation.

Now all the biologists speak in unison. "So, are you convinced that an idealist metaphysic—that everything is made of consciousness—is needed for biology?"

I decide to accept their challenge. Idealist biology, here we come. "Are you guys going to help me, though? My knowledge of biology is quite shaky." It is my turn to be honest.

"Of course, we will help you—we are you." They say in unison as I wake up from my dream.

The Need for Biology Within Consciousness

Today in biology there is indeed a crisis of philosophy and a deeper crisis of identity. Many biologists recognize the need for movement in the philosophical doldrums. Book after book—on evolution, on morphogenesis, on the nature of life itself—talks about the need for new ideas. But they all fall short because they are unable to shake their dependence on the philosophy of material realism. Material realism holds that all causes reside in matter, and that these causes manifest in causally and locally determined fashions that are completely objective. All things including life are thought to be manifestations of matter and its chemistry. Ideas such as living systems' having causal efficacy over their environment are poo-pooed as vitalism—a proposal of a vital force apart from matter. But everything is made of matter, so how can there be a vital force?

Vitalism does sound like dualism. The vital force is proposed as part of a dual world apart from matter. Such a dual world's exerting forces in our world cannot be justified for such elementary reasons as the conservation of energy. We always find the energy of our

world to be constant. This could not be the case if forces from another world acted on objects of this world. But dualism is not the only way to think about the causal efficacy of life. Monism does not imply material monism.

In material realism, only matter (and its correlates, energy and fields) is real. Consciousness and objects of its mentation are all epiphenomena. According to the philosophy of monistic idealism, consciousness, not matter, is the ground of being. All are phenomena in consciousness, and that includes matter and self–objects and subjects, if you will–on equal footing. In this philosophy, consciousness can act on matter, but not dualistically. Matter initially exists as forms of possibility out of which consciousness self-referentially chooses and recognizes a particular facet, which then becomes apparently manifest as the object of experience of a subject/self that arises simultaneously. In the process of choosing and recognizing, consciousness identifies with specific configurations of matter that we call the living and the conscious.

Modern physics already tells us that matter ultimately consists of possibility forms, not forms of determinism assumed in material realism. This new mechanics of matter is quantum mechanics, but until now its application to biological systems has been at a minimum. The conventional wisdom is that in the realm of the macro, quantum behavior turns to determined behavior–an idea called the *correspondence principle.* But I have already demonstrated the importance of quantum creativity in psychology in Part 5.

The question is, Do biological forms follow a deterministic mechanics? Or are there indications that there are plays of possibility even at the macro level of life? There are. There are subtle behaviors in biological evolution and morphogenesis that suggest a quantum connection. And if there is a quantum connection, if there are possibility waves in living matter in the macro scale of the living cell, then consciousness can supervene (transcendentally intervene). It is my contention that in the process of this supervention into complex matter, the one monistic consciousness divides itself into two parts: life (subject) and its environment (object). In the process, consciousness also identifies with the subject-part that we call life and regards itself separate from the object/environment. Life thus has potentially the causal efficacy of consciousness itself–choice and recognition.

So are the anomalies of biology–nature of life, symbiosis of the totality of life and its environment on earth, evolution of new species, repetition of form in morphogenesis, the relation of biological forms and their environment–are they all the consequence of conscious choice and recognition from the domain of quantum possibilities? The purpose of Part 6 of this book is to build a good case for an affirmative answer to this question.

But why? What have we gained with an idealist biology, aside from the removal of a few anomalies from a sophisticated scientific discipline? Why insist on bringing such idealist science to the foreground of popular attention before its authenticity is scientifically established? There are good reasons.

Traditional biology has given us an image of ourselves that is profoundly false–the image that we are competitive creatures of self-survival with no other purpose. This lack of purposiveness is leading to a confusion of values. For even as conscious beings we do have the tendency for becoming conditioned (that ubiquitous correspondence principle). Thus, the tendency toward becoming a valueless hedonistic society of robots. An idealist science is the creative movement of consciousness away from this tendency.

Still another grave consequence of the material realist biology is the regarding of the body-mind as a machine, which has made medical science into a very limited science. "The body is a machine, the mind is a machine, the soul is a machine," declared the biologist Jaques Monod. In this view, physicians must look upon themselves as no more than automobile mechanics. But there is ample evidence that there is creativity in healing, as there is in life. An idealist biology—biology within the primacy of consciousness—proposes creativity in addition to determined-machine behavior for living bodies. And the time has come to acknowledge and use this creative capacity as we begin an era of unprecedented availability of healing and medicine for people in the 21st century.

CHAPTER 27

Toward a Paradigm Shift in Biology

Before the 20th century, Newton's laws of motion provided the paradigmatic umbrella for all phenomena of physics: mechanics, electromagnetism, statistical mechanics, and so forth. In biology, neo-Darwinism and molecular biology provide such a paradigm today.

When inconsistencies and anomalies begin to show in an old paradigm, and the paradigm begins to look like a patchwork quilt due to attempts to explain away the difficulties, it is time for a paradigm shift. The biggest example of such a paradigm shift is the shift in the way we do physics from Newtonian physics to quantum physics. At the end of the nineteenth century, the Newtonian paradigm of classical physics was burdened by only a few inconsistencies. But a rapid discovery of several anomalous phenomena increased the inconsistencies to such a voluminous proportion that the whole paradigm had to give way to new thinking by the 1920s.

In this way, the situation in biology is quite similar. But this is not as obvious, because biology is not mathematical and it is a little easier to rationalize away inconsistencies via verbal arguments. However, it is the anomalous data that eventually breaks the camel's back.

Paradigms come with a metaphysics that provides the underlying tenets, the givens, of the paradigm thinking. For the current paradigm of biology, the underlying metaphysics was borrowed from classical physics.

Newton's laws are mathematical and give a strict, causal deterministic description of

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physical systems. Given initial conditions on position and velocity and the causal agents (forces) acting on the system, the laws of motion determine the future of all systems. Want to know the whereabouts of Jupiter in the future? Here is the recipe: determine the position and velocity of the planet now. These initial conditions, the knowledge of the nature of gravity and Newton's laws of motion, and a good computer will enable you to calculate the position of the planet for a very long time.

In biology, there is no mathematical theory, let alone one comparable to Newton's. Yet the tenet of causal determinism was accepted as dogma because it was assumed that ultimately biology is just physics, only more complicated.

Newtonian physics is also a strictly objective description. Furthermore, local causes, causes that travel through space and time obeying the speed-of-light limit, are considered enough.

It is a somewhat surprising fact that the tenets of objectivity and locality were accepted in biology without much thought given to them. This is surprising because from inside, we know that life has a certain feel to it, it has a subjective (and likely nonlocal) component that cannot be ignored.

Meanwhile, as Newtonian physics has become the paradigmatic basis for physics, chemists have been struggling with the idea of a material monism—that all things are made of matter (and energy and force fields). The success of molecular biology in describing the mechanism behind the running of a living cell influenced biologists enough to now take material monism seriously as a tenet.

Beginning in the 1960s, physicists also began talking about a fifth tenet of their worldview, epiphenomenalism, according to which, phenomena such as life and consciousness are epiphenomena of matter. These last two tenets—materialism and epiphenomenalism—became, of course, part of the biological gospel as well.

To summarize, the current two-pronged paradigm of biology—molecular biology/neo-Darwinism—is based on Newtonian ideas and the following five tenets of metaphysics, referred to as material realism:

1. Causal determinism
2. Objectivity
3. Locality
4. Material monism
5. Epiphenomenalism

It is important to be clear on the basic tenets of current biology when discussing inconsistencies and anomalies of the current biological paradigm. The anomalies discussed in the last chapter are anomalies because these data and ideas threaten to contradict the above tenets.

Let's trace the Newtonian basis of the current paradigm. Newton's classical physics is based on the observation that physical systems exist on their own in states of stasis (inertia) and change from this state is brought about by agents of change (forces). The paradigm gives the proper description of both the stasis of the system, the statics, and the formula for change that forms the dynamics (for the Newtonian paradigm, this was Newton's laws of motion). In biology, molecular biology gives the description of the

stasis, and the Darwinian idea of variation/natural selection is the agent of change. Let's first briefly discuss the molecular biology of a living cell.

Inside a Living Cell

Let's look at the structure of a living cell and its functioning from the point of view of present-day molecular biology. First of all, there is a wall, a semi-permeable membrane that separates the inside of the cell from the outside, but not completely. Through the cell wall, the cell can take in food energy for its functioning, and also dispose of waste products—the result of its metabolism. Inside, there are various molecules, some small, but especially there are the large molecules, macromolecules consisting of many smaller pieces—these are the proteins, the DNA, and the RNA (ribonucleic acid) that make the living cell special. In the simplest of living cells, the prokaryotes, all the molecules freely interact as they float in a watery medium called the cytoplasm. In the body of the more evolved cell, the eukaryote, the DNA is separated from the rest—the cytoplasm and all—within the wall of a nucleus.

The proteins carry out the major functions of the cell, which can be stated simply as the net production and maintenance of order. The DNA carries within it the genes—the blueprint for protein-making. The genes determine the sequence of the component amino acids that make up proteins. It is these blueprints written in the universal genetic code that hold the key to heredity. The RNA are intermediaries needed for the process of protein-making from the blueprint that the DNA provides.

The nucleic acid molecules are instrumental in carrying out the reproductive function of the cell. Interestingly, the proteins play an essential role as catalysts for the self-replicating roles of the nucleic acid macromolecules.

Books on molecular biology lay out the detailed functioning of the living cell—a self-sustaining system of order and reproduction—starting from the basic premise above, and they explain a large amount of important data. Looked upon from this molecular point of view, it seems that biology has been more or less reduced to chemistry, and hence to physics (the unity of chemistry and physics is now well established; this is one of the great achievements of quantum mechanics).

With the molecular biological understanding of the functions of living cell, have we a complete understanding of what life is? Well, a cell can self-maintain and self-reproduce, but so can other systems.

Consider, for example, another system that can produce and maintain order and can reproduce itself—a flame. What does the flame not have that a living cell has? Obviously life must be something more than self-sustenance and reproduction, but what is that something? That something may be evolution, which is a most interesting characteristic of life. I once asked a colleague, a biologist, What distinguishes life from nonlife? His immediate answer was, Evolution. Many biologists feel the same way. We have fossil evidence that life started on earth as one-cell objects and has evolved to the present enormous complexity, giving us the tree of life. Evolution is a spectacular characteristic of life, no doubt.

"The world is our laboratory," said the great biologist Julian Huxley. "Evolution

itself is our guinea pig." How is the guinea pig studied? How is evolution incorporated in biology? Neo-Darwinism.

Neo-Darwinism

Charles Darwin himself (and his contemporary, biologist Alfred Russell Wallace) formulated the original idea of how change comes about in biological systems. According to Darwin, it is partly a mechanism that produces variation in the biological system, and partly a mechanism that selects from among these variations that enable the organism to survive. It is a theory of variation/natural selection in response to a play of chance and necessity.

Let's use the modern language of a revised Darwinism, called neo-Darwinism, which combines the ideas of Darwin, genetics, and modern population and molecular biologies. According to this view, random changes occur in the status quo of the hereditary material of life—the genes (which are components of the DNA molecule). A change in a gene is expressed in a new trait (technically called a new phenotype)—a variation. The form with the new trait, by virtue of fecundity, competes against the old forms (and other new forms created in the same way) for survival—a necessity, because of the finiteness of resources in a finite environment. Nature sorts and selects from among these phenotypes new biological species with plentiful fecundity that are better adapted to the environment. And nature acts within the bounds of physical description—it, too, is nothing but atoms and molecules. Also, nature pays for the entropy decrease for the evolution of life by increasing the entropy of the environment by the necessary amount.

Chance and necessity. Chance produces variation. The survival necessity manifests as natural selection. It is a beautiful and elegant theory. To many biologists, Darwin's theory provides an adequate basis for a paradigm of biology (neo-Darwinism) that is sufficiently unique and yet does not require any new physical laws, no extension of the existing paradigm of physics, and no new metaphysics beyond the materialist and mechanistic one—everything is made of atoms, and life is a machine. Or is it?

Reductionism and Holism

Material realists also quite commonly use a methodology called reductionism. The idea is to reduce macro systems to the mechanics of their micro components. It is the use of reductionist methodology that has convinced so many biologists that biology is nothing but physics and chemistry. In this mechanistic reductionist view, life is reducible to mechanical laws. The laws of physics (and chemistry) that explain the behavior of nonliving things should also explain all there is to explain about living things, according to this view. Materialist biologists glibly propagate their serious prejudices in one-liners that sound like doggerels:

George Wald: A physicist is an atom's way of knowing about atoms.

Edward O. Wilson: The organism is only DNA's way of making more DNA.
Melvin Konner: A person is only a gene's way of making another gene.

In short, these biologists are saying that all phenomena at the macro level, including life and consciousness, are epiphenomena of some micro level of matter.

Is the science of life just the chemistry of its macromolecules, proteins, and nucleic acids? Can biology be reduced to chemistry and hence to physics and its laws that manifest in the interactions of atoms and molecules that give us chemistry? Many biologists believe that such a reduction is possible, and they want to prove it by assembling a living cell starting from some of the ingredients. "The ultimate aim of the modern movement in biology is in fact to explain all biology in terms of physics and chemistry," declares the biologist Francis Crick, the co-discoverer of the double-helix structure of the DNA. But there are problems in this way of thinking.

The movie-maker Woody Allen used to do a comedy routine a long time ago in which he goes to England and buys a Rolls Royce but does not want to pay import duty. So he dismantles the car and packs it in a whole bunch of suitcases. After returning to the United States, he tries to reassemble the Rolls. To his dismay, however, he makes sewing machines (actually several thousand of them), a tank, even an airplane, but never the original car.

So one of the problems of blatant reductionism in biology is the sheer enormity of the complexity of what we are trying to reassemble. But is that all there is, complexity, that separates us from finding a satisfactory reductionist explanation of life? No, complexity is important, but there is more to life than just complexity of the assembly.

Fortunately, reductionism is not fully entrenched. There is an opposing group of biologists who base their thinking on what is called holism—whole is more than the total of the parts. According to holism, life cannot be reduced to the micro level physics and chemistry, because it is an emergent phenomenon crucially dependent on the complexity at the macro level. Life has a wholeness that cannot be reduced to the mechanical laws of physics and chemistry of the constituents of a living system. Holists try to supplement the current reductionist biology by completing what they see as the sensible epiphenomenalist program—the theory of emergence of holistic aspects of life.

The debate between the reductionists and holists go on and on. Robert Wright has called this split of views the great divide, and no bridge is in sight.

Holism

The reductionist view is widely used in both molecular biological description of the stasis of life and the neo-Darwinian theory of evolution, but such use could be myopic.

Let's go back to the discussion of the differences between the reductionists' and the holists' approach to life. Can living behavior, such as self-maintenance, self-reproduction, and evolution, be expected of mechanical, rule-bound machines? The reductionists say yes. The living machine is made of complex, interacting parts. Once we have figured out the laws of the parts, we have figured out the whole, they say. The laws of interaction of the parts are, in principle, given by the laws of physics and chemistry of their parts. And so on it goes. The whole is nothing but the sum of the parts including their interactions.

Holists disagree with the reductionists, of course. The whole is more than the sum of the parts, they maintain, and life is a good example of this holistic principle. There are new laws, new organizing principles, that come into being for the whole, new mysteries that cannot always be predicted, and that cannot be reduced to or understood in terms of the interaction of the parts.

But isn't the job of science to hunt down nature's mysteries? Biology is a science, should it involve unpredictable mysteries? ask the reductionists.

Science does sometimes demystify, but that's not all of it. Science, above all, is a search for truth, the holists retort. If truth is mystery, science will have to accept it. For one thing, we are blatantly disregarding what makes a living cell alive in any real sense by buying into molecular biology, say Chilean biologists Humberto Maturana and Francisco Varela. That is the cell's autonomy. Living beings have causal efficacy. They are their own bosses, as mysterious as their origins may be. They dance to the tune of their own holistic causal autonomy that comes with life. This tune is compatible with the laws of physics but is not reducible to it.

Varela and Maturana feel that the autonomy is a result of *autopoiesis*, the self-organization of life. The Greek word *auto* means self and *poiesis* means creation (the word "poetry" has the same etymological origin, by the way). Thus, autopoiesis is self-creation, self-organization. Reductionists, of course, deny causal autonomy to all biological beings, be it the single-cell bacteria or humans.

Holists can also point out difficulties with neo-Darwinism. Take mutations, for example. Do they really produce variations on which natural selection can act to bring about new species? Yes, mutations take place, but such mutations by and large seem to take the system toward the worse, not toward the better. Even if occasionally a potentially beneficial mutation might happen, by itself it would not be enough to produce a really novel trait, and hence it would be selected against. Only relatively insignificant mutations will make the cut. And because mutations are selected for or against individuals, accumulation of small changes leading to a big change is a myth. So you see, the variation/selection procedure is designed to maintain the status quo, not evolution. So say the holists.

The idea of natural selection to drive evolution is difficult to uphold also because natural selection acts at the (phenotypical) macro level, whereas the variability exists at the micro, genetic level. This would not be a problem if there were a one-to-one correspondence between the genes of an organism (the genotype) and the phenotype (implicitly assumed above). But let's face it, there is no such one-to-one correspondence. It takes several genes for a given phenotype expression (trait), and a given gene may take part in several such expressions.

There has been some progress on developing a holist theory of self-organization and evolution. The central ideas are based on cellular automata and chaos theory.

Self-Reproducing Automata and the Game of Life

Imagine paraders on a field during half-time of a football game. The paraders are displaying a variety of patterns by holding up component cards. One moment, the face of President Kennedy appears, only to be replaced by that of Martin Luther King, Jr., and

Marilyn Monroe. And then the faces blink out, and a picture of bluebirds of happiness shows up.

How do the paraders do it? They do it by holding up the cards in a succession according to some prior arrangement. But that's just the beginning of an idea. The physicist John von Neumann, the mathematician and inventor of modern-day computers, might have devised the cellular automata theory from this kind of modest idea.

Suppose, instead of a prior arrangement, the paraders just followed some simple rule for what card to hold up next. For example, the cards could be simple colors—red, white, and yellow—and the instruction that each person hold up the previous color that was held by the majority of his or her four nearest neighbors (to the right, left, front, and back). Suppose they started with the white face of Monroe with her blonde hair and a hint of her red blouse. In the next frame the face is certain to be swept away by some other display of form in that color combination, but we may very well get some other orderly form in some future frame.

Now the paraders (and with them, we) are playing a computer game called "Cellular Automaton," which von Neumann pioneered, a game in which adjacent computer spaces or cells (but don't confuse them with biological cells), following some simple rules of interactions, make patterns. Von Neumann invented this game in order to be able to say something definitive about whether or under what conditions machines are able to self-reproduce.

The cells can be one- or two-dimensional, but for a simple illustration, consider a one-dimensional array (Figure 27.1) where each cell has only two nearest neighbors. Instead of three colors, let's use a two-valuedness to specify the state of the cell—empty or occupied, with 0 for empty and 1 for occupied. The state of the whole array at any time will be completely specified by stating which cells are occupied and which empty.

Next let's make up a simple rule for the progression of the game. If the neighbors of a cell are both occupied or both unoccupied in the previous frame, we will assign the cell a value 0 (that is, it will be unoccupied), otherwise, we will assign the cell a value 1 (that is, occupied). So if we start with the lower state shown in Figure 27.1, we get the upper state in the next frame.

That's the game, say the mathematicians who play with cellular automata. Now, here's something interesting. The rules of the game involve only each cell's nearest neighbors, so they are obviously local rules, but the game can nevertheless create global patterns.

The patterns generated are much richer for two-dimensional arrays. The mathematician John Conway built a computer game called "life," in which patterns can sustain and reproduce themselves, much like a living entity.

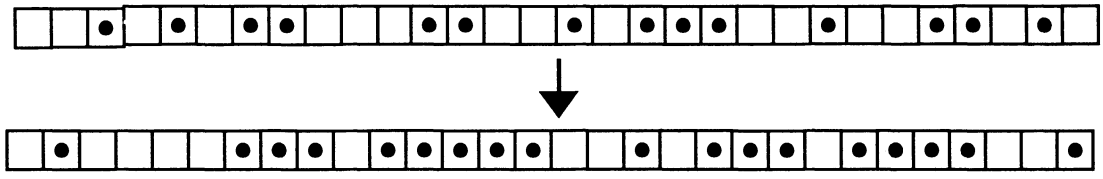

Figure 27.1
Cellular automaton. See text for explanation.

Have you heard of a Turing machine? That's the universal computer that translates one set of symbols to another—universal because its functioning does not depend on any particular physical representation? An abacus or an Apple Mac—both are Turing machines.

An important mathematical result of the cellular automata theory is that a certain class of automata is equivalent to a Turing machine. Von Neumann adapted the idea of Turing's universal computer to prove the existence of a universal self-reproducer. What he found is that such a universal self-reproducer must have both hardware (the processor of information) and software (the container of information), software of instructions of how to make not only new hardware but also the software itself.

Von Neumann proved the existence of self-reproducing automata, provided a very high threshold of complexity is reached. So unfortunately, the actual physical construction of a self-reproducer per his theory is probably beyond human reach. In other words, his theory will probably never be experimentally verified.

But here is the value of von Neumann's work. He clearly saw the role of both a self-maintaining system and a self-replicating system in a truly self-reproducing system. You have to have both for self-reproduction. The progress of molecular biology in the '50s shows that von Neumann was right. The proteins of a living cell play the role of maintenance manager (computer hardware) and the DNA plays the role of replicators (software) in the workings of the living cell. And the rules these entities obey are pretty much the same as those von Neumann derived from theoretical considerations.

So where do holists fit in? Holists attempt to make models of self-organization with cellular automata. But will such self-organizing automata have autonomy? Can you hear the anachronism in automata being autonomic? Patience, says the holist. This will make sense when you learn chaos theory.

Chaos Theory

A surgeon, a physicist, and a lawyer are arguing about the oldest profession in the world—about God's profession, that is.

"God must be a surgeon. Look, He is said to have made Eve from Adam's rib. That must have been pretty fancy surgery, wouldn't you say?" The surgeon argues.

"Nonsense," says the physicist. "God has to be a chaos theorist. How else would She create the world from all that chaos of the early universe?"

"Ah," coos the lawyer, "But who created the chaos?"

One can argue whether God is a chaos theorist or not, but one cannot argue with the idea that chaos dynamics—how order is created out of chaos, and how old order breaks down and, in its place, new order takes hold—has important things to say about biological systems. Chaos theory is about the dynamics of chaotic systems. I have already discussed chaos theory in Volume I of this book, but here is a recap.

A chaotic system, although it obeys Newton's laws and is therefore deterministic, is highly sensitive to the initial conditions—so much so, that its future behavior cannot be predicted for long. The errors of the initial knowledge of the initial conditions keep multiplying exponentially, making predictions of the future less and less accurate. We now

know that this is the reason for the essential long-term unpredictability of our weather system. Irrespective of how well we collect the initial data or how big a computer we have to make our calculations, weather predictions can always go wrong. The fluttering of the wings of a butterfly in Oregon changes the weather in New York, so to speak.

A second significant thing about the dynamics of chaotic systems is that, when operating away from equilibrium, a system can exhibit almost cyclical behavior or patterns of form, but there is something special about each of these forms—no two forms are exactly alike, only qualitatively so. So there is chaos, unpredictability, but there is also order within chaos, a self-organization that comes about from the feedback that's built into the dynamics. These aspects are reminiscent of some of the properties of living systems.

Think of ordinary order near equilibrium as lakes in mountain valleys. They are beautiful, but mountain climbers know that the most beautiful lakes lie on the top of the mountain—in this case, the mountain of entropy, the scientific name for disorder, of course.

The extreme sensitivity of chaotic systems to initial conditions and the emergence of order within chaos, it is said, give chaotic systems the aura of autonomy. Although ultimately it is determined chaos, when new order emerges unpredictably and holistically from inside the system, an experience of autonomy may emerge concomitantly, it is argued.

A third characteristic makes chaos theory suitable for thinking about biological evolution. Chaotic systems may settle down at a certain order, spellbound by what mathematicians endearingly call an "attractor." But when a parameter of the dynamics changes, the system is able to jump out of the basin of its attractor, only to fall into a new basin of a new attractor. This process is called bifurcation, and its similarity with evolution is obvious. An old genetic order breaks down due to copying error, mutation, and what not. The system jumps out of one attractor basin into another. A new genetic order giving rise to a new species comes into place.

Chaos theory also goes beyond conventional molecular biology in giving a better description of cellular stasis that may include autonomy. The biologist Stuart Kaufman, one of the world's exponents of complexity theory, tries to make models of self-organizing automata using holistic principles. For him, self-organization is the key to life. If we can find a truly self-organizing system of automata, it will dance to its own tune, it will have autonomy, Kaufman says. Can automata be autonomous? If we deal with automata via chaos theory, we get behavior that appears to be autonomy. At least this much progress has been made.

Are the holists right then, that life is an emergent principle, emerging from the self-organization of certain basic, programmed entities? Surely, chaos theory makes it clear that such a self-organizing system may appear to be autonomous, the telling characteristic of life.

Unfortunately, to develop a new paradigm of biology on the basis of holism, chaos theory notwithstanding, has not been successful. Most anomalies mentioned in Chapter 26 remain.

Is life self-maintenance, self-reproduction, evolution, self-organization, and apparent autonomy? What is missing? What is life? Let's take up this question in more details in the next chapter.

Bibliography

Alberts, B., et al. *Molecular Biology of the Cell.* NY: Garland, 1983.
Davies, P. *The Cosmic Blueprint.* NY: Simon & Schuster, 1988.
Kaufman, S. *The Origins of Order.* Oxford, UK: Oxford University Press, 1993.
Mayr, E. *The Growth of Biological Thought.* Cambridge, MA: Harvard University Press, 1982.

CHAPTER 28

What Is Life?

Once a man went to a famous biology department of an equally famous university and began asking the question, "What is life?" of all the professors. None of the professors could answer him to his satisfaction. Eventually, the chairman of the department, a Nobel laureate in biology, appeared on the scene. When asked the question "What is life?" he took the man aside and said, "My colleagues hold me in such high regard that I could not tell you this in front of them. But, you see, even I really do not know what life is."

Admittedly, I made up the story, altering a Buddhist tale along the same line, but many scientists would agree that the spirit of the story is true. Biologists (except perhaps for Humberto Maturana) cannot define life; not reductionists, and not holists.

Biology is no doubt about how life works and how life evolves. But the basic theme ought to be, What is life? In music you start with "do re mi." It makes sense to start with definitions.

But biologists seem to have a different motto. They seem to say, call a rose by any other name, it will give the same fragrance. Why put yourself in a straightjacket trying to rigidly define life? Instead, they count the ways that distinguish a living thing.

So what distinguishes the living from the nonliving? When you go to a restaurant, do you get curious as to whether the plants on display are live or not? Most likely, you don't try to figure it out with the help of any definition, you do it by the feel. You may also intuit that being alive has a very special feel to it.

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But feel is not a very scientific concept. Instead, one of the qualities of life that biologists center on is self-maintenance. Living systems maintain themselves in a certain homeostasis via metabolism. They take in food and convert it to biological order. They reject the waste products of the process to the environment. Living systems are able to make more order starting with less.

Try self-reproduction as a second distinction of life, biologists say. A living system can divide into two systems of the same class—that's called reproduction. But notice that reproduction is more general than mere copying (no errors) or replicating (errors allowed).

A most interesting characteristic of life is evolution. We have fossil evidence that life started on earth as one-cell organisms and has evolved to the present, enormously complex organisms that include us. Evolution is the most spectacular characteristic of life, many biologists believe.

A non-scientist will be tempted to include death in this distinguishing list. If we don't give water to a plastic plant, starving won't do a thing to it, but a living plant will die without water.

But death won't do, says the biologist. Death is the cessation of life processes. It depends on life for its definition, not the other way around. Besides, single-cell bacteria don't really die; they just divide themselves. Even more confusing is the fact that some bacteria seem to "die" when dehydrated, but we can revive them with water. This is similar to unplugging a mechanical machine and then reviving it by turning the electrical juice back on.

So biologists in the main, the reductionists, try to stick to self-maintenance, self-reproduction, and evolution when it comes to distinguishing life from nonlife, things they think they can explain. To this list, the holists add one more distinguishing facet—self-organization, the idea that life organizes itself, and apparent autonomy. There you have it. Life is the convergence of four unusual features of matter: self-maintenance, self-reproduction, evolution, and self-organization. Individually, we find these features in other nonliving systems, but collectively they make life appear to be something special. And this is the way it should be! After all, life isn't really different from non-life, according to most biologists. But it is a very special emergent epiphenomenon.

Alas, it is not that simple. Critics can point out that the evolution of biological systems is purposive; living systems evolve toward some sort of design. But how do we include the idea of purpose or design within a Newtonian deterministic framework? Can there be a design without a designer?

And to say life is self-organizing or autonomous when all the causal efficacy is believed to lie with the elementary particles of matter is downright confusing. Living systems can do things by themselves, they have causal efficacy. Many of us will agree with this assertion. But for the majority of biologists today, holists and reductionists, nothing has autonomy in the ultimate sense. Biologists *en masse* have bought into the philosophy of determinism from physics. According to this philosophy, the behavior of all things is causally determined by the forces acting on them and by their initial conditions—where they are and what their velocity is at some initial time—and living things are no exception. So many holists are happy with chaos theory of apparent autonomy.

But can we really deny that in the living and the conscious, there is downward causation, causation imposed by the organism as a whole from the top downward, in addition

to the upward causation from the reductive material components (the elementary particles)? In humans, downward causation is revealed in our free will and creativity. But even the lowly bacteria have it, as in the phenomenon of directed mutation (see Chapter 26).

Living systems have a tendency to maintain integrity; they distinguish themselves from their environment. If you put some mud on a stone, the stone does not reject it. But do the same with your cat and see what happens. More seriously, an embryo is often able to counter and bypass harmful intruders, additions (or subtractions), at least early in its development, and grow into its normal form. This phenomenon, called regulation, is an example of integrity not found in nonliving nature (see Chapter 30). Clearly also, there is meaning in living form that is not contained in physical laws. In general, in living beings there is self-reference, an experience of separateness between life and environment. And also, for self-conscious beings such as we, there is an experience of separateness between subject and object.

When we talk of the living, we need concepts such as survival, pleasure, pain, intention, and so forth. These words are not in the vocabulary of the laws of physics; we never need such words to describe the nonliving. Molecules of the nonliving show no tendency to survive or to love (although some biologists debate that). Nor do we need the concepts of pleasure and pain to describe molecular behavior. Instead, these concepts describe the contexts and meanings behind the contents of living.

And finally, there is an inside feel to life, we all know what it is to be alive from inside.

More on Purpose

Can new order come out of material systems just because they are open, chaotic systems away from equilibrium? Do open, chaotic systems exhibit new emergent order, new laws of becoming, that wasn't present before? What is lacking in this exciting suggestive dynamics as a model of life?

One outstanding shortcoming of neo-Darwinism is also lacking in chaos theory. It is the more-or-less irreversible generation of complexity. Biological evolution is irreversibly geared toward higher and higher complexity. Seldom do we find any regression toward simplicity. In neo-Darwinism, random variations cannot give us one-way movement toward complexity, because randomness is a two-way street—random variations can lead to simplicity as well as complexity. And as the physicist Paul Davies says, natural selection selects for fecundity and survival, not for complexity. Likewise, chaos is determined chaos, ultimately a chaotic system obeys Newtonian deterministic laws and these laws are time-reversible—they take the system in either direction of time without any preference. But irreversible biological evolution toward greater and greater complexity implies an arrow of time.

You may think, Oh, but we never see events going backward in time, anyway. But that is only because there is an apparent irreversibility that fools you. The apparent irreversibility of Newtonian systems arises from the overwhelming odds that exist against retracing the path to the system's initial, orderly configuration. So it seems that entropy always increases. But biological systems exhibit an irreversibility in the opposite direction, to-

ward more complexity and less entropy. How do we explain that with Newtonian (time-reversible) physics? This time even considerations of probability don't help.

Face it, when old order breaks up in a chaotic system and it hops from one attractor basin to another, it is equally likely that the new basin will correspond to more or less order.

So many biologists deny that evolution has a preference toward complexity. There is no hierarchy among living creatures, they say. All life forms are equal regardless of how high they occur in the tree of life. But is this a valid denial, when the same biologists very likely subscribe to a human-over-nature way of living?

Evolution toward greater and greater complexity is not the only signpost of purposiveness. Consider the evolution of complex organs, such as the eye. In Darwinian terms, this would require natural selection acting on many little variations. But individually, some of these variations would have no survival benefit, some of the variations needed might actually be detrimental to survival when taken individually. Thus, reason demands that they would be selected against. So it is unlikely that small, individually useless or harmful variations can accommodate and together produce macro level traits of importance, such as the eye. In this way, the evolution of an organ like the eye smacks of purposiveness. This issue is further complicated by the recent finding that all eyes descended from one single prototype. In neo-Darwinist dogma, all changes come about partly by accident, so eyes should evolve independently in different species and there should be more than one prototype.

There is also the case of the evolution of instinctual behavior, such as a cat's grooming itself, that smacks of purposiveness. How many random mutations are necessary for rewiring the neural connections for a new instinct?

Suppose we capitulate on this failure of material realism to explain a biological arrow of time toward complexity to invoke a grand designer, God, as some Christian theologians do. God is conceived as a dualistic Being who creates the universe and evolves its creatures in His grand design, to serve His purpose. But there is a problems with this image, too.

What have we really gained by proposing that the evolution of the universe, including those of life and mind, is just the fulfillment of a grand design—the purpose of God? This philosophy, called *teleology*, is just determinism in reverse. Instead of initial conditions running the universe, as assumed in Newtonian physics and conventional biology, now final conditions are running it. Take your pick!

The philosopher Henry Bergson saw this very clearly when he said:

> The doctrine of teleology, in its extreme form, as we find in Leibniz, for example, implies that things and beings merely realize a program previously arranged. But there is nothing unforeseen; time is useless again. As in the mechanistic [deterministic] hypothesis here again it is supposed all is given. Finalism thus understood is only inverted mechanism.

Materialists undermine teleology by giving the purposiveness of evolution the name teleonomy, meaning apparent purposiveness, as if grand design. Bergson's answer was more constructive: a creative universe. Things manifest in the world, new order comes to pass, completely independently of past conditions and future dictations.

The Creative Purpose of Consciousness

But again, there is a problem with the creative universe from the materialist point of view. Creativity needs an evaluation of the product—its meaning arises only in the mind of an observer. Is there any sense in ascribing creativity to matter, even if we are prepared to give up the deterministic laws of Newton? (Don't be shocked! Newton's laws have been replaced by quantum mechanics anyway; further modifications are certainly not unthinkable.)

The answer I propose is Bergsonian in spirit, but its basis is the philosophy of monistic idealism, according to which consciousness—not matter—is the ground of being. And the tool of the proposal is quantum physics, an application of quantum laws, including ideas of quantum measurement, as needed to the affairs of life and mind.

The lesson of Part 5 of this book is that the way to solve the famous paradoxes of quantum physics is to invoke idealist philosophy based on one monistic consciousness. This solution has a bonus—the combination of quantum physics and idealist philosophy applied to the brain-mind—an application aptly called idealist science—solves additionally the thorny issues of the mind-brain problem (see Part 5).

For quantum objects, initial conditions do not forever determine an object's motion. Instead, every time we observe the object, it gets to have a new beginning. Yet the behavior of massive objects seems to be deterministic. In the quantum world, there is thus the enlarged scope of both creative and determined behavior. We will see that the evolution of life and mind indeed consists of both these modalities, creative and deterministic!

So I am proposing that consciousness in its creative modality is the illusive, organizing principle that holists vainly seek in matter. It is consciousness that brings forth life from non-life. It is consciousness that seeks new life and creatively founds it in the phenomenon of speciation, eventually leading to human beings. It is consciousness that ascribes meaning to what goes on in the phenomena of life and mind, and guides their evolution both historically and developmentally.

Yes, there is purpose in evolution, but it is not a predetermined purpose. As in creativity, the purpose is a vague intuition that there is much that is unconscious, there is much in unmanifest consciousness that has not found expression yet. The process of creation and evolution is meant for consciousness to see itself, to reveal itself to itself. As things manifest, some of these intuitive themes have become clear. Some of them were codified by Plato—the platonic archetypes of love, truth, beauty, the perfect solids, and all that—as early as 500 B. C. Others, such as inertia, other material laws of physics, and mathematical theorems, are relatively recent revelations.

Since antiquity idealists in India have pictured the world as a play of consciousness. The part that observes (subject) is called *purusha*; the part that is observed (object), *prakriti*. In one very picturesque description, *purusha* (conceived as male) is following *prakriti* (conceived as a female), but *prakriti* is illusive. Every time *purusha* gets a glimpse, *prakriti* changes form and escapes again, and the play of discovery goes on.

It is like this in evolution. There is creativity in the evolution of biological forms. There is creativity in the development of our bodies and our minds. And there is creativity in the way the collection of mind-bodies develop into societies and cultures. There is also much determined behavior. Determined behavior sometimes is innate (such as the

inertia of matter discovered by Galileo and Newton). Other times it is the price of experience, as for our egoic experience (as re-discovered by Pavlov, Watson, and Skinner). Still other times it's a result of nature's exerting a selection pressure toward adaptation (natural selection, as discovered by Darwin). So far, we have concentrated on the science of determined behavior; in a sense that has been right. Determined behavior is easier to study—it's objective, it's stable, and amenable to scientific scrutiny. But now the time has come for studying the creative elements of the universe—how creativity brings forth the forever new in the affairs of life and mind; how creativity shapes our own becoming.

Consciousness and Order Within Chaos

I have spoken of chaos dynamics as a possibility for generating order within chaos, but it is a fact that consciousness also can generate order in spite of chaos. When you clean up your desk after a week's accumulation of unfinished business, you are creating order, and that in spite of the chaos—the sweat and all that—in your body. And behold! The order you have created has meaning and purposiveness. Papers relating to a specific field of activity are neatly arranged at one place with the purpose that you will be able to pay coherent attention to them later. In contrast, when a purely material deterministic mechanism creates order (and the mechanism of chaos theory is no exception), there is no meaning and purposiveness in that order—there cannot be. So if you see meaning and purposiveness in life and its evolution, you already know that consciousness is an essential player here. (This does not exclude the possibility that chaos dynamics plays a role as well, but only under conscious guidance.)

There is one great advantage to having consciousness in the game of production of order. Ordinarily, producing order from disorder, going uphill against the entropy law, costs energy. Remember the paradox of Maxwell's demon? Consider a vessel full of air at uniform temperature and divided into two compartments by means of a partition with a trap door (Figure 28.1(a)). Molecules of various speeds (shown as arrows—longer arrows mean greater speed) are equally distributed in the two compartments, a consequence of uniform temperature. Now suppose a demon sits on the trap door and changes the distribution by opening the trap door whenever a fast molecule approaches from the left, but closing it whenever a slow molecule does the same, and vice versa from the right. Very soon the distribution of molecules is changed to that of Figure 28.1(b). Now there is more order, and a decrease of entropy. How did this happen? What Clerk Maxwell thought was a paradox was resolved by physicist Leon Brillouin who pointed out that it takes energy for the demon to see which molecule is fast and which slow, and to raise and lower the trap door.

But we have seen that in the creative process, quantum unconscious processing is involved, and this hardly costs energy. In quantum creativity, we let the order accumulate without collapse, as possibilities, choosing all the elements of the new order in one fell swoop and avoiding the energy cost of the entropy violation if we chose each element of the new order individually.

Is life a reductionist or a holist phenomenon? Neither reductionist nor holist theo-

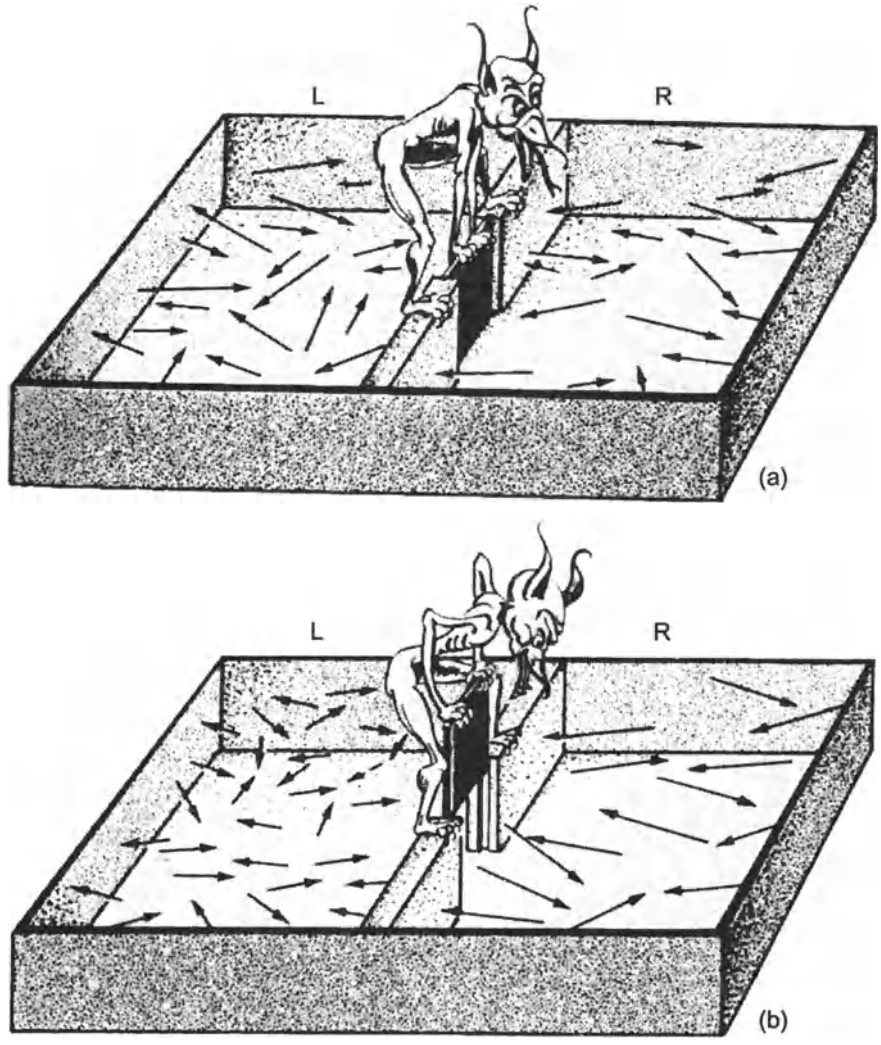

Figure 28.1
(a) Random assembly of slow (small arrows) and fast (large arrows) molecules in both compartments L and R. The arrows denote the velocity of the molecules.
(b) The slow molecules have been separated from the fast ones by the demon and his trap-door trick. Leon Brillouin showed that this is impossible to accomplish without increasing the entropy of the environment and expending energy. Information as to which molecules are slow and which are fast costs entropy as well as energy.

ries explain all the relevant facts of life and its evolution. I submit that this is because both of these classes of theory hold on to the idea of material supremacy. This may be most obvious in the context of the purposiveness of life, but the truth is that there are other clear inconsistencies in materialist (and even holistic) attempts to explain life and its evolution. Not surprisingly, there are also anomalous data already introduced in Chapter 26.

The Question of Causal Efficacy of Life

Most biologists believe, reductionists or holists, that life is chemistry. Reductionists say that life can be reduced to processes and properties of the parts. Holists say that life is an emergent epiphenomenon of chemistry, but of the whole. When an assembly of certain chemicals reaches a certain threshold of complexity—wham-o! It is alive. It can self-organize, it can self-maintain, and it can self-reproduce.

But what makes a single-cell creature alive? Clearly, it has established an integrity in its relationship to its environment, an integrity it preserves until it dies. It has a self as opposed to its environment. But how does it get its self?

If everything is made up of one level of things, matter, then we can never have a separation such as the living self and the non-living environment. Sure, you can talk about molecules and atoms as hierarchies, but molecules don't manipulate atoms, they form a simple hierarchy. Ultimately molecules are completely determined by atomic interactions. But we suspect that the self-organization, self-maintenance, and self-reproduction that life represents manipulates the environment for itself. Life has causal efficacy.

And we suspect that we have causal efficacy. Our creative acts, including the creative acts of materialist biologists, would not be potent without this causal efficacy. If we were one level of things, how could we experience the world as object and ourselves as cognizing subjects?

It is a fact that the description of neurophysiological phenomena naturally involves consciousness, subjectivity. In realist science, the tendency has been to downplay and eventually sever this consciousness connection. But the question can be asked: are we missing something in the process of objectifying neurophysiological phenomena? The philosopher Robert Efron thinks so.

> The reductionist attacks the definition and usage of every word, which has historically referred to an action of a living entity: "memory," "reflex," "free will," "cognition," and so forth. He then redefines the same word so that it will be applicable to an action of an inanimate entity. By using this epistemological technique he deludes himself into thinking that inanimate entities have the same properties that are found in living organisms, that a common denominator has been found, and that the problem of reduction is "solved." The solution is primitive animism expressed in scientific jargon.

What the reductionist method misses is "living." It takes living out of life. And the holists don't do much better by positing living as emergent epiphenomena of matter.

Downward Causation

Let's think in terms of a computer analogy. In a computer, it is possible simultaneously to think of complementary ways: we can think from a software point of view, and say that programs causally affect other programs in computer functioning. At the same time, we can say that at the hardware level, molecules act on molecules via physical forces.

And surely, the software "program-like" behavior is completely consistent with the hardware "law-like" behavior.

But of course, nobody would claim that the software laws or program-like behavior are derivable from the hardware laws. For the computer, we know that we, the programmer, use the physical hardware to perform software functions, as we do in a myriad other situations: writing, doing arithmetic on an abacus, and so forth. Program-like behavior is purposive and meaningful, it reflects our purposes and our meanings. Admittedly, it is confusing because program-like behavior is algorithmic and therefore deterministic, resembling law-like behavior of nonliving matter. So it is tempting to ignore the purposiveness and the meaningfulness of the programs and forget the programmer.

In other words, in the computers that we build we are imposing downward causation from a higher level of a hierarchy. Where is the equivalent of that in the hierarchical organization of biological beings within a basic materialist/mechanist point of view? What is the equivalent of a programmer in the biological computer?

One possible answer is "boundary conditions." The quanta or grains of light—the photons—from a laser behave in a cohesive, unidirectional pattern because of mirrors at the ends of the lasing chamber that constrain the photons' freedom of movement inside the laser. This is an example of downward causation imposed by conditions at the boundary. Unfortunately, it is not at all clear if such boundary conditions are enough to impose downward causation to the degree that law-like behavior of molecules will be converted into programmed macro behavior in biological being. For example, there is not an iota of evidence to suggest that macromolecules of nucleic acid develop their survival necessity because they are confined by a cell wall.

It seems that neither the physical scientist nor the biologist has figured out how the law-like behavior of nonliving matter, by itself, changes into the programmed behavior of the living. All that the recent research with genetic engineering has managed to show is that we can take bits and pieces of programmed living matter from nature and manipulate them. But in our laboratories, we have never been able to convert law-like behavior into programmed behavior without a programmer, without our conscious interference. Similarly, all the work with cellular automata proves only that complicated program-like behavior can arise from relatively simple behavior. No doubt, matter is programmable within its law-like behavior, but can it self-propel from one (law-like behavior) to the other (program-like behavior) without any help from consciousness? The answer seems to be no.

We have been barking up the wrong tree! Material realism is an inadequate philosophy for the living, because it is becoming clear that it is not even adequate for the nonliving. But suppose we jump beyond material realism and embrace monistic idealism? What then? Now there is a programmer—consciousness is the programmer that can use matter to write the programs, the software laws that govern the biological kingdoms. And not only that, the door is opened to understand the self-reference of life that distinguishes it from insentient matter.

Can we invite consciousness into science without stepping out of physical theories? Without giving up any hope of reconciling biology with physics at the theory level? The point largely unrecognized by biological theorists is that physics itself, with the development of quantum mechanics, is calling for consciousness in order to resolve its paradoxes. Quantum mechanics gives us possibilities. The discoverer of cellular automata, John von

Neumann himself, proposed that it has to be consciousness that brings to us the manifest world from these possibilities. When physics is suitably pivoted toward consciousness, such a physics can also find reconciliation with biology. In the process, both biology and physics become part of an extended paradigm of science—an idealist, consciousness-based science. These issues are taken up in more detail in subsequent chapters.

Law-Like and Program-Like Behavior

The causal laws of physics are deterministic laws. Given initial conditions on position and velocity and the causal agents (forces) acting on the system, the laws of motion determine the future of all nonliving systems. Even when the behavior of the system is very sensitive to initial conditions (chaotic systems), the causal laws of physics enable us to predict the system if we make occasional mid-course corrections. Witness how accurate our weather predictions have become, at least in the short term. Even for submicroscopic quantum systems, statistical causal laws can predict their behavior and evolution as long as we are dealing with a large enough number of objects (such is the case for most practical things in the world of the nonliving). Nonliving systems are therefore cause-driven, and I term their behavior law-like.

But there is something peculiar about living systems—purposive evolution, causal autonomy, meaningful behavior, and so forth. Some biologists correctly recognize behavior such as survival as an example of program-like behavior—behavior that follows logical, step-by-step rules of instruction having a purpose. They also see the evolution of complex organs like the eye as examples of the purposive nature of biological evolution. But this is not the majority opinion.

There are other examples of purposive, programmed behavior in the affairs of the living. Perhaps the greatest example of programmed behavior exists in morphogenesis—the development of the adult form from the zygote. But biologists cannot find the instructions for morphogenesis written anywhere, there is nothing like the genetic code (which is an instruction manual for making proteins—the functional molecules of life) for making form out of the embryo. So, in the case of morphogenesis, many more biologists talk about programs and program-like behavior.

If there are programs, who or what writes these programs? Can the programs come about from the law-like behavior of the underlying molecules, the hardware? Consider the human-made computer. At the level of the electronic hardware, electrons act on electrons via physical forces following physical laws—this is law-like behavior. At the software level, we have programs acting on programs. Certainly, the two levels of behavior are consistent; one would even agree that the cause of the programmed behavior may be found in the underlying motion of electrons, but this has not been shown to be the complete story. Far from it! Are the laws by which the computer programs operate derivable from the hardware laws of the electrons? Are the laws by which the programs of morphogenesis operate derivable from the laws of physics and chemistry? And what of the meaning of the content that the programs generate, the integrity of living forms? These are million-dollar questions that materialist scientists cannot answer.

As users, we know what happens with our silicon computers. We, the programmers, use the physical hardware of the computer to run software programs to carry out our

purpose. These programs have nothing to do with the laws of the electronic hardware. The programs carry the meaning and purpose we give them. Why should it be any different for the program-like behavior of life in nature? Why should we not recognize the role of consciousness in life?

The point is that computers process symbols, but we the programmers ascribe the meaning to the symbols. You may ask why we don't have some other symbols for meaning, call them meaning symbols. As I have argued before, then we would need further symbols for the meaning of the meaning, *ad infinitum*.

To summarize, we, the programmers, by imposing downward causation, provide the meanings, contexts, and purposes of computer programs. Similarly, we must recognize the downwardly causal role of consciousness in the programming of the biological computers involved in evolution and morphogenesis.

We depend on our creativity to write really innovative programs to carry out our purpose with our computers. Is there evidence for such creativity of the programmer in the evolution of life? Repeated evidence. All really big changes in complexity, such as the transition from reptiles to birds or from primates to humans, are not explained by a Darwinian gradual variation/selection mechanism. Instead, they show the quantum leap of a creative consciousness' choosing among many simultaneous potential variations. Punctuation marks in evolution, no-fossil evidence in periods of very rapid change, are evidence of such creative interventions (see Chapter 29).

The real difference between the nonliving and the living is the manifest causal role that the programmer, consciousness, plays in the latter. In the process, consciousness identifies with the living, cognizing itself as separate from the environment; it is this identification that lends to life its integrity, its wholeness. The behavior of the nonliving is law-like; operationally, it can be talked about without invoking consciousness, creating a camouflage of apparent objectivity. But the hope for an objective science of the living is doomed from the beginning, because it is clear that its program-like, purposive behavior is not derivable from the law-like behavior of its constituents. Furthermore, only creativity can really change the contexts of the programs in any major way. And finally, the wholeness of the living reflects the wholeness of the consciousness that identifies with it.

Once we recognize the role of consciousness in life, it is easy to understand life's meaning—consciousness is the meaning. Life evolves to manifest consciousness in its ever-proliferating richness.

Consciousness As the Creative Organizing Principle of Life

We return to our nagging question, Is the science of life just the chemistry of its macromolecules, proteins, and DNA? Can biology be reduced to chemistry, and hence to physics and its laws that manifest in the interactions of atoms and molecules that give us chemistry?

In life, there is living; and it is always somebody that lives, as manifestation of consciousness. Without living, there is no life; we cannot separate the two. But how does living enter an assembly of molecules? This is the fundamental question that neither reductionists nor holists can answer.

There is no *a priori* reason to presuppose that the explanations of biological phenomena can be given on the basis of the known laws of physics, which admittedly tend to be deterministic at the macro level. Earlier in this century two eminent physicists, Erwin Schrödinger and Niels Bohr, both thought that the explanation of life would require some new principle outside of the laws of physics and chemistry. But in the '50s, molecular biology made a quantum leap—the discovery of the double helix structure of DNA and the cracking of the genetic code opened up such new areas of research in biology that a long leave was taken from the search for new laws. Only recently, with the discovery of new anomalies, have some biologists become open to even considering the question of new laws. But unfortunately, they always restrict their context of thinking to material realism.

Can life and consciousness—the two astounding aspects of living beings—be emergent epiphenomena? Can the question of becoming that is central to life be answered staying within the confines of materialism? Can life ever be demonstrated to arrive from non-life? Can consciousness?

I say, No. I submit that the telling peculiarity of the living is the special feel of life from inside—that special cognition that manifests as the ability to distinguish oneself from the environment. The evolution of such living beings through reproduction is progressive not only in the adaptive sense, but also in some absolute sense. For the evolution of life, the context of living, that special "feel" of life, keeps shifting and becoming more and more multifaceted and sophisticated. Today, in the computer laboratory, we experiment with self-reproducing programs of "life." But such programs can only reproduce themselves, they cannot creatively change the context of their being.

But if living things are not only material, programmed machines, what are they? The traditional biologist will cry "vitalism" at this point. Vitalists used to argue that there is a special "vital energy" that is responsible for life, that represents life in living matter. The difficulty with the vitalist view is that it is dualistic—a world of life separate from the world of matter is postulated. And dualism is easy to refute. How does life interact with matter? If the interaction involves energy exchange, we know that the energy of the material world is conserved—the total amount of energy in a process always remains constant. If there was a vital world exchanging energy with the material world, surely this would show up as a deficit or excess in our energy ledger. If there is no direct interaction between the vital world and the material world, then some other body must mediate their interaction. But where is such an agency?

There is an alternative to both the material machine model and dualistic vitalism. And that is a model based on monistic idealism—the philosophy that consciousness is the ground of being. Why do living organisms have subject-object cognition of their environment? Because consciousness collapses the possibility wave involved with living, identifying with that which manifests as the living being. How do living things evolve creatively? Because consciousness brings in an essential creativity and purposiveness that are fundamentally different from the determined behavior that matter seems to exhibit. How does the vital energy body interact with the physical? Consciousness mediates their interaction (see also Chapter 30), and in a way that avoids any energy exchange.

Materialistic physics, of course, is quantitative, subject to complete prediction and control. Thus biologists, who desire similar powers of prediction and control for their

science, naturally suffer from physics envy. If biology has creative aspects, then obviously, some of the biological phenomena will be beyond quantitative explanation—but so what? Current biological models carefully avoid certain phenomena, for example, our subjective experiences. But it is these phenomena that make biology special.

It is sometimes pointed out that all measurements in biology are carried out by physical instruments, which obey physical laws. Since the only measurements that make sense in biology are physical measurements, the only science that is necessary to understand biology is the material laws of physics. As the discussion above makes clear, this attitude is limiting biology from the consideration of those phenomena that make biology special. To use Abraham Maslow's metaphor, if you have only a hammer to investigate the world, you begin to look at the world as consisting of nails and their epiphenomena. Niels Bohr, when he suggested the application of complementarity in the phenomena of living, warned us about the difficulty we have—what we study in the laboratory with physical instruments is necessarily the characteristics of the nonliving. We must supplement them with complementary studies of the systems that include living, while the systems are living. Can we perform experiments that include and reflect the quality that we call living? Of course we can. But we have to go beyond the context of the molecular biological laboratory.

The truth is, science progresses by analogies and metaphors only to a certain extent. Beyond that we must invoke creative revolution-paradigm shift. The physics model of molecular biology and neo-Darwinism based on the analogies and metaphors of classical physics has gone as far as it can, but it cannot answer the questions raised here, and it cannot explain the anomalous data reported earlier (Chapter 26) satisfactorily and fully. It cannot incorporate purposiveness, or explain the biological arrow of time for evolution toward increasing complexity. All classical models, including the one based on chaos theory, are about behavior, what is seen outside. These models are unable to look at life from the inside. The time is right for a paradigm shift in biology. It is time to develop biology within consciousness, as an idealist science.

In fact, this should not be too startling. Because even physics is fundamentally an idealist science. As shown in Part 5, the interpretation of quantum mechanics and the resolution of quantum paradoxes is achieved in the most consistent and straightforward fashion within an idealist science of primacy of consciousness. And reassuringly, the equations of physics do not need to be modified for nonliving, non self-referential systems—consciousness enters only when we measure such physical systems. Therefore, realist conventional science works for physics and chemistry except for measurement paradoxes. For biology, a science of self-referential beings, idealist science gives us many new results, among them explanations of the anomalies discussed before. But here again, materialist biology is recovered in the limit of what is a correspondence principle (see later).

In the next three chapters, we develop the new idealist biology (we can also call it quantum biology) in some detail, sometimes even technical detail, so that the contention that the anomalies and paradoxes of biology can be solved by developing a new biology within the primacy of consciousness can be fully justified.

CHAPTER 29

The Quantum Theory of Punctuated Equilibrium

Whence comes the evolution of biological order? Is the neo-Darwinian mechanism of variation/natural selection adequate for describing the evolution of all biological order, or are there additional organizing principles? This is a question that biologists have tried to address for decades, usually within the overall context of scientific realism, but no satisfactory organizing principle has emerged from all this research. In this chapter we will consider a radically new approach based on the idealist interpretation of quantum mechanics in which consciousness, not matter, is the ground of being. Thus, the question before us is, Can it be that consciousness is the organizing principle that is missing from the realist approach to the evolution of biological order?

The neo-Darwinian theory of evolution claims that all evolution can be explained with a chance mutation/natural selection, dual, gradual process. But an alternative view of evolution has gained prominence in recent years, a view that there are two modes of evolution with two different tempos and themes.

That there are at least two tempos or modes of divergence-producing evolution is actually an old idea. In this view, aside from gradual evolution via accumulation of the minor genetic mutations of micro evolution, there are also quantum leaps in macro evolution—a macro evolutionary change brought about in a relatively short time.

The biologist Gaylord Simpson thought that this quantum evolution "is a special,

A. Goswami, *The Physicists' View of Nature*
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more-or-less extreme and limiting case of phyletic evolution [the evolution of various biological groups]." He thought quantum evolution might provide an explanation of fossil records that indicate periods of normal, phyletic evolution of many groups of organisms, while there is scant or no fossil record of the groups' origins. In the same vein, the notorious "missing links" in the fossil data of the evolutionary tree between groups may be explained by quantum evolution.

Similarly, the biologist Ernst Mayr propounded the occurrence of genetic revolutions in bottleneck situations where a population has been reduced to a small size. If a particular bottleneck population survives the genetic revolution, it becomes the founder of a new group. Another biologist, Theodore Dobzhansky, has expounded in a similar vein the concept of transcendent evolution, consisting of giant leaps (such as from prokaryotes to eukaryotes).

More recently, paleontologists Niles Eldredge, Steven J. Gould, and Vernon Grant have proposed that the periods of rapid quantum evolution coincide with speciation events. Eldredge and Gould have used the phrase "punctuated equilibrium" for this idea, for they think that in between punctuation there is only evolutionary stasis. Grant has proposed the name "quantum speciation" for the phenomenon of speciation through rapid quantum evolution.

The purpose of this chapter is first to show that the terms "quantum speciation" and "quantum evolution," in general, are most appropriate for the phenomenon of rapid macro evolution, because they may involve quantum physical processes at the micro level and quantum measurement at the macro level. We will use the phrase "quantum speciation" to denote a speciation event through the explicitly quantum mechanism (to be elaborated below). In contrast, gradual speciation events will be called Darwinian or classical. We will use the phrase "quantum evolution" more inclusively to denote a quantum leap of the quantum process that leads to a change of species, family, order, class, or phylum.

Although their phrase "punctuated equilibrium" is not as appropriate as quantum speciation (or quantum evolution) for the phenomena under consideration, Eldredge and Gould made several good points. They correctly have emphasized causal discontinuity over tempo (as in Simpson's work). Says Gould, "There is a discontinuity in cause and explanation between adaptation in local populations and speciation; they represent two distinct, though interacting, levels of evolution." And Gould has also emphasized that even if the basic processes—mutation, selection, genetic drift—may be the same in the two levels of evolution, gradual and quantum, "they work in different ways." In this chapter I will show that there is indeed causal discontinuity involved in quantum speciation and evolution, and that the basic processes of neo-Darwinism must work here in different ways, namely with a quantum mechanism, in order to be plausible. I will also show that the quantum theory explored here gives a picture of evolution very close to what Gould and Eldredge envisioned—rapid, discontinuous, quantum evolution followed by long periods of homeostasis consisting of gradual, continuous, classical (in the sense of physics) evolution, a view with which even Ernst Mayr, the most authoritative figure in evolution theory today, agrees. Essentially, this is a creativity model for evolution. Following Piaget, I have recently argued that human development follows a pattern of alternating periods of rapid, creative bursts of quantum origin and homeostasis when classical, continuous changes prevail (see Chapter 23).

There are other important shortcomings of the neo-Darwinist synthesis. As mentioned before, Darwinian variability, from which selection has to be made, occurs at the micro level of the genes. But natural selection—the survival of the fittest—takes place at the macro phenotypical level of the organism. This is not a problem if genes and the micro level have a one-to-one correspondence with macro phenotypical traits. Unfortunately, such a correspondence has not been demonstrated. We will see that in a quantum approach to evolution, the micro and macro levels are bridged in a natural way.

Another (already mentioned) problem with neo-Darwinist theory is that random processes play a crucial role, but random processes can take evolution toward the less complex as easily as toward the more complex. In other words, random processes do not lead to an evolutionary arrow of time. Can the arrow of time come from natural selection? This too is doubtful because, as the physicist Paul Davies has argued, natural selection selects for fecundity, not for complexity. I will show that an idealist approach to biology gives us an arrow of time.

Finally, the idealist approach arrives at a clear understanding of the nature of life itself.

A Review of Existing Theories of Quantum Evolution

One of the most puzzling questions about gradualism is this: How can random step-by-step changes in the genetic structure, which are selected step-by-step, also explain the many coherent changes that must converge to give us a novel, complex function that often distinguishes a new species? One solution is a complementary mode of evolution with a different tempo and with a different mechanism from Darwin's. But what is the mechanism?

Unfortunately, the biggest problem with the acceptance of the idea of quantum speciation, and of quantum evolution in general, is the somewhat anemic nature of the contingency-based mechanisms that have so far been suggested for the phenomena. In one such model, quantum evolution requires a small population, such as a small, geographically isolated colony. In such populations, due to inbreeding and to fortuitous environmental preadaptation (adaptation through already-selected response in the gene pool), it is expected that mutations leading to a new species will survive.

However, quantum speciation has been known not to be restricted to isolated populations, but to occur even in large, continuous populations. Also, how does the selective advantage of mutations in an isolated group come about? Individual mutations are still expected to be vastly harmful. Could it be that the individual mutations are selectively neutral, and yet a group of them together may have the slight, selective advantage required (see later)?

Consider a second model favored by many punctuationalists—species selection, in which it is assumed that the selection pressure somehow acts on the entire group (group traits) rather than the individual members (individual traits). But the proponents of species selection are unable to suggest specific new mechanisms. The key question remains unanswered. How does an entire group of traits characterizing a species escape individual selection for each of the individual traits?

The question is, Can we find a mechanism that is not restricted to the geographical isolationism, and at the same time gives a genuine, novel mechanism for species selection—that is, selection operating at the level of an entire group of traits that defines a species?

Now I can state my reasons for investigating a quantum theory within the primacy of consciousness for quantum speciation and evolution. Quantum mechanics is characterized by both of the aspects of evolutionary change we are looking for:

1) A theory for a discontinuous quantum leap in evolution, with or without geographical isolation. Discontinuous movement is a fundamental aspect of quantum systems.

2) A way of propagating mutated change without selection or adaptation. In quantum mechanics, this happens in the form of the propagation of superpositions of possibilities in between collapse events.

A most spectacular signature of any quantum movement is the possibility of nonlocal correlation, which is now experimentally established. Is there any evidence of nonlocal correlation in biological order and evolution? There is. I will mention two cases.

First, nonlocality must play a role in co-evolution where two entirely different species must evolve together in order to better survive. Many plants and ants have symbiotic relationships: Plants provide the ants with shelter and food, and ants drive away other insects and harmful animals, and even help keep away other vegetation. In such symbiotic relationships co-evolution is most readily seen. For example, many plants independently evolve seeds with an edible, fatty lobe as a reward for ants, who in turn reward the plants by carrying away the seeds to their homes, eating the fatty part and leaving the seeds to sprout in places that are favorable for the plant to grow. The conventional argument—that each species puts selection pressure on the random variations of the other as part of the other's environment—misses something, namely the extreme, low probability of beneficial mutation. Again a more plausible answer is that beneficial mutations are held in limbo until some later, opportune time when both are ready to make a sudden change. And the sudden change seems to be nonlocal in character.

Second, there is the intriguing phenomenon of morphogenesis. All cells have the same information for protein making—but they wait before turning on specific functions at some appropriate time. It is as if certain functions remain in limbo until, simultaneously in spatially separated body parts, there is a consensual "yes," as if there is a proverbial prince whose kissing the princess awakens selective parts of the sleeping kingdom. Again, this action could not be local, and quantum nonlocal correlations must be playing a role (also see Chapter 30).

Quantum Measurement and Quantum Evolution

Let me once again stress the fundamental problem with the theories toward a mechanism of quantum evolution. Evidence suggests that genetic drift must be overwhelmingly neutral. Selection more often does not act on individual, random mutations (if it did, chances are overwhelming that the mutation would be eliminated). And yet, if a group of

mutations somehow escapes individual selection, they might accumulate a selective advantage as a group, and then the group of mutations would be favorably selected by natural selection.

A radical new way of looking is needed, and I suggest that quantum mechanics and ideas of the idealist interpretation of quantum measurement can provide such a new way of theorizing. The stifling assumption here is that every genetic mutation of micro evolution must correspond to a real, manifest phenotypical change, and the only ways it can escape elimination through natural selection are through geographic isolation or selective neutrality, as suggested by the biologist M. Kimura. But there is a third possibility that quantum mechanics and the idealist quantum measurement theory developed in this book permits.

Gene mutations, either point mutations caused by radiation or some kind of chromosomal inversion or rearrangement, are quantum phenomena. For example, a point mutation by a radioactive agent would produce a state that is a superposition of possibilities—new and old—the probabilities of each of the possibilities are correlated to the probability function of the radioactive decay. In the case of chromosomal reshuffling, a superposition of possibilities results because, as the physicist W.M. Elssasser has pointed out, there is a great amount of "degeneracy" involved—existence of states with the same or nearly the same energy. Biologists, based on their bias of scientific realism, are assuming that the superposition obtained by either of the two mechanisms above is immediately collapsed to one of the outcomes according to the probabilities assigned, but this is against the grain of quantum mechanics. According to the quantum measurement theory above, no such collapse takes place until consciousness self-referentially chooses from among the possibilities offered by the appropriate quantum dynamics.

In the case of a living cell's having to deal with a superposition of possibilities at the gene level, what does this entail? Only consciousness can collapse the superposition of possibilities that the cell offers, and only in a self-referential manner. We are thus led to the hypothesis that what we call "life" is the result of the self-referential choice by consciousness. The self-organization in a cell that enables the cell to distinguish itself from its environment, the breakdown of the whole (consciousness and its possibilities) into living system plus environment, is a tangled interplay of choice (from the superposition) and the arena of living in which the "chosen" facet manifests.

So when does consciousness choose? As we have seen in our discussion of quantum measurement in Chapter 18, consciousness chooses not at the micro level, but only upon amplification. Clearly, an amplification of the micro physical mutation has to take place before choice occurs. In the case of the cell, this amplification involves a phenotypical expression of the genetic change existing in potentia. Thus, there is no collapse, no choice among the possibilities given rise by the mutations, until a collage of possibilities have accumulated to deserve phenotypical expression. The phenotypical expression involves a series of quantum measurement apparatuses—the regulator genes, structural genes, RNA, and proteins.

So, here then is the solution to our problem. Drift consists of neutral, mutated genes, but they are not manifest mutations as Kimura suggests. They are possibilities, passed on via heredity to subsequent generations. Other mutations accumulate on top of these uncollapsed superpositions. The states become more and more complicated superposi-

tions, until a time arises when the measurement apparatuses mentioned above make one or more new amino acids, which change proteins that thusly lead to a new phenotypical expression—all this still in possibility. (Things can causally affect things in possibility; that is how quantum dynamics works!) And now consciousness self-referentially chooses among all the possibilities—new and old—occasionally choosing the new. If the resulting, new self-organization also prevents interbreeding with the old, we have a new species—quantum speciation.

Notice how in this idealist scenario an entire set of mutations at the micro level, enough to find phenotypical macro-expression and to make a quantum leap to a new novel species, becomes manifest. Of course, natural selection has the final say, but now the entire set of mutations is being selected from, and thus species selection is given a plausible mechanism. In this way, the usual puzzles of neo-Darwinism, namely, how micro evolution connects to macro evolution, and how novel speciation occurs (such as those that change an entire class or phylum), are solved. Neo-Darwinism cannot explain why we never find the fossil intermediaries for the transition between reptiles and birds. How the last reptile can lay an egg that hatches a creature that flies away as a bird is a complete puzzle in that theory. But the quantum theory explains this as an example of quantum evolution—a quantum leap on a grand scale, requiring much unconscious processing of many parallelly mutated genes in potentia and the corresponding phenotypical expressions, also in potentia. At the same time, the quantum-idealist scenario is completely consistent with the philosophy of species selection and more. It completes the program by providing an explicit mechanism for species selection.

Specifying when the self-referential collapse occurs makes macro quantum evolution possible because (detrimental) selection of intermediate stages is eliminated. But how about probabilities? Quantum dynamics holds that probabilities do not significantly improve, regardless of whether or not collapse occurs in the intermediate stages. In other words, the probability of collapse remains small. This is true of any creative process. What helps in the case of creative biological evolution is the long time available for unconscious processing. Over and above this, one also has to invoke "morphogenetic fields" that contain the specific form (defining the species) that consciousness is awaiting. Collapse is triggered when a "resonance" takes place between the archetypal form and its manifestation (see Chapter 30).

Many theorists assume that, for all practical purposes, "coherent" superpositions at the macroscopic level lose their phase relationships (technically, this is called decoherence) by interacting with their environment. However, for a confined system like the quantum systems in the living cell, I do not believe there is any appreciable decoherence.

Comparison With the Case of the Brain: The Relation of Neo-Darwinism with the Present Theory

Let's now compare the quantum biological model with a similar model developed for the self-reference of the brain to gain further insight into the former.

As discussed in Chapter 18, idealist science posits that the brain consists of a dual

quantum-system/measurement-aid apparatus. In general, the states of the brain exist as superpositions of possibilities. The one, transcendent consciousness self-referentially collapses an actual event from these possibilities by freely choosing among them. The self-reference arises because the relationship of a quantum system and its measurement-aid apparatus is a tangled, hierarchical one. In the process of self-reference, consciousness identifies with the brain—an identity that I call the quantum self. And the primary process of collapse, where there is free choice (all the constraints are accounted for in the quantum dynamics of the possibility waves, namely, in what possibilities are offered by the brain), I call the quantum modality. Eventually, in the brain, environmental conditioning produces a classical modality of operation where consciousness identifies itself with a conditioned set of operations in a particular brain. This identity is the ego.

I have already discussed the idea that environmental conditioning is the result of the reflection of the experience due to a repeated stimulus in the mirror of memory by positing that in the presence of memory, the Schrödinger equation for a self-referential quantum-system/measurement-aid apparatus acquires a nonlinear term. Indeed, the effect of the feedback from the nonlinear term is that learned responses take on enhanced probability weighting. Thus, the original freedom of choice available is compromised in favor of past conditioning. In the limit of infinite conditioning of the quantum modality, there is no freedom of choice at all in the collapse of an event from the quantum possibilities. Now determinism holds, and the behavior of the system is Newtonian. I call this the classical modality of behavior. In this limit, the idealist theory corresponds to behaviorism for the brain.

In the conditioned, classical modality, we usually display a set of predictable behaviors arising from a set of learned repertoires. In the presence of new environmental stimuli, we may vary the repertoire we use to suit the situation (adaptation). In contrast, only the quantum modality enables us to engage in creativity—the discovery of a truly new context by the quantum collapse from a previously uncollapsed superposition. The new context then enriches the repertoire and can be used subsequently for adaptation.

Analogically, we can see that the event of quantum speciation or quantum evolution is an event of creativity for a living cell. Here the quantum superposition of possibilities plays a crucial role for evolution to occur, and there is complete freedom of choice for the collapse of the creative new form, so long as the quantum dynamics of mutation has made the necessary possibilities available. We should also expect a conditioned modality for life and its evolution. Since, as has been noted by many authors, all biological life is connected to some first cell through heredity, conditioning operates on the whole tree of life. Hence, we get stasis-like behavior in the intervals between quantum speciation and evolution episodes. This has been noted already by punctuationalists such as Gould. The similarity of normal Darwinian evolution within stasis periods to behaviorism of the brain has also been noted by many authors. When a certain variety of gypsy moth undergoes a change of color to adapt to environmental pollution, it is a Darwinian change from one already-selected mode to another (adaptation). The required genes were already in the gene pool of the species. But this is not the case when humans evolve from the primates. Then the choice is made from never-before-selected gene mutations (and their phenotypical expressions) in potentia.

If the organism is already adapted to the environment, the quantum modality is sup-

pressed, and we find stasis dominating the scene. But in the presence of rapid changes of the environment, such as in the Cambrian period, many existing species become extinct, those that could not genetically assimilate the changes demanded by the environment. Still others adapt through existing already-selected responses available in the gene pool (preadaptation). A few take the creative leap to a new species, giving us quantum speciation and, sometimes, even more novel quantum evolution. Clearly, also, with the progress of time and later species' having more and more adapted gene pools, the need for a creative response to changes in the environment at the species level decreases. Hence there is less and less new quantum speciation and quantum evolution, as found empirically.

I am thus proposing that, like the brain, the living cell is fundamentally a self-referential system consisting of a quantum system and measuring-aid apparatuses. Due to conditioning over millions of years, the quantum behavior of the system is suppressed, except for relatively rare quantum speciation (or even rarer quantum evolution) events. This is the reason that cell biologists need not usually refer to quantum processes to describe the stasis of the cell; classical deterministic explanations suffice. And this conditioned suppression of the quantum behavior is a more fundamental reason for why, as evolution progresses, there is less and less proliferation of family, order, class, and phyla.

Apparent Purposiveness and Directionality in Evolution

The current picture also gives a nice compromise solution to the dilemma of apparent purposiveness in evolution. The usual, neo-Darwinian gradual evolution is causally driven. What is present now as organism and as environment exerts selection pressure and determines the future. Purpose is usually seen as a final cause that pulls the organism from the future. Seen in this way, purpose is hard to rationalize with causal determinism. But the idea of creativity in evolution opens the door to a new way of looking at purposiveness.

In purposiveness as final cause, the future is already determined in all detail. This is the aspect that does not jibe with antecedent causes' also playing a role, causes such as chance mutation or environmental selection effects. But if the purposiveness is creative, what then? If consciousness chooses creatively, opportunistically taking advantage of contingencies, and purposively, contingent upon environmental changes, toward greater and greater complexity, then there would be a directionality in evolution, as we indeed find to be the case. Yes, consciousness is creating with some definite, final form in mind, as dictated by the morphogenetic fields (see Chapter 30), but the path to the final form is creative and not predetermined, as in teleology.

Note that this does not mean either that evolution cannot proceed toward less complex some of the time. Consciousness is free to choose from available possible mutations the quantum possibility pattern that leads to less complex species. It is the overall purposiveness toward complexity that gives rise to the biological arrow of time. In the monistic idealist literature, this purposiveness is referred to as the desire of consciousness to see itself in fullness.

It is in the injection of creative purposiveness and a net one-way evolution toward greater and greater complexity that the current model is superior to chaos theoretic mod-

els. Determined chaos can give new order, but there is no arrow of time in that theory, so progress can go both ways equally. But quantum measurement by consciousness is irreversible (see Chapter 25).

The Nature of Life

As already noted, the components of the self-referential living cell are the quantum system and its measurement-aid apparatuses—the nucleic acids and proteins. And they form a tangled hierarchy from which arises the self-reference that separates life from its environment. Consciousness also identifies with life because of the veil brought about by the tangled hierarchy. And as life evolves, the identity that consciousness assumes proliferates, giving us the tree of life. But it is one life's creatively evolving through various stages of homeostasis and quantum leaps. This one life identity of consciousness that evolves in correlation with its environment is similar in some ways to the idea of Gaia proposed by the chemist James Lovelock and the biologist Lynn Margulis. More recently, astronomer and author Arne Wyller has also propounded a similar view of planetary consciousness.

Thus, in the new theory, self-reference and creative evolution are the defining characteristics of life, not self-organization, not self-maintenance, not even self-reproduction. These are all natural extensions of self-reference and self-evolution alternating through periods of creativity and homeostasis.

Also, in a sense, the present theory fulfills the vision of the organismic view of life propounded, for example, by the Berkeley biologist Richard Strohman. Consciousness identifies with all the different homeostases in the progression of life: life itself—the culmination of prebiotic evolution in potentia; the species—the culmination of quantum speciation and subsequent conditioned homeostasis; and finally the individual—the culmination of morphogenesis.

Bibliography

Dobzhansky, T. *The Biology of Ultimate Concern*. NY: New American Library, 1967.

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World*. NY: Tarcher/Putnam, 1993.

Goswami, A. "Consciousness and Biological Order: Toward a Quantum Theory of Life and Its Evolution." *Integrative Physiological and Behavioral Science*, Vol. 32, pp. 86-100, 1997.

Kimura, M. *The Neutral Theory of Molecular Evolution*. Cambridge: Cambridge University Press, 1983.

Lovelock, J.E. *Gaia: A New Look at Life on Earth*. Oxford: Oxford University Press, 1982.

Lovelock, J.E., and Margulis, L. In *Global Ecology: Toward a Science of the Biosphere* (M.B. Rambler, ed.). London: Jones and Bartlett, 1984.

Sheldrake, R. *A New Science of Life*. LA: Tarcher, 1981.

Simpson, G.G. *The Major Features of Evolution*. NY: Columbia University Press, 1953.

Wyller, A. *The Creating Consciousness: Science as the Language of God*. Denver, CO: MacMurray & Beck, 1999.

CHAPTER 30

Evolution and Morphogenesis

Morphogenesis—the growth of form from a single-cell embryo—is a problem of biological order of unprecedented precision timing of correlated events of both spatial and temporal nature. One doesn't see anything like this in dealing with inanimate matter. Naturally, beginning with Erwin Schrödinger, an impressive group of scientists has suggested that the currently known laws of physics may not be enough to explain morphogenesis. Many biologists have propounded the idea of a morphogenetic field—a condition of space that retains the memory of the form that the embryo evolves towards under the guidance of the fields. But these earlier works hold on to the concept of local fields, and also to the materialist belief in upward causation—the supremacy of matter as the cause of everything.

But morphogenesis has overtones of teleology—the idea that some final purpose is driving the system—to many, and the biologist Rupert Sheldrake has injected new principles into the old idea of morphogenetic fields to incorporate teleology, nonlocality, and downward causation. His morphogenetic fields are purposive and nonlocal. They are not material—they are capable of downward causation in matter through a new principle called "morphic resonance." According to Sheldrake, as soon as a new form comes about, it sets up its own field, which is continually reinforced with its ongoing replication, thus explaining the "memory" exhibited in morphogenesis. However, there is the question of the source of the morphogenetic fields that resonate with matter, an implicit dualism.

In this chapter I will show that, although dualistic in its original form, Sheldrake's ideas can be given sound footing on the basis of quantum principles applied in the conceptualization of the living cell within the context of idealist science, science within consciousness, a science based on the primacy of consciousness.

A. Goswami, *The Physicists' View of Nature*
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Sheldrake's Theory: How Form Is Remembered

A real problem of morphogenesis is nonlocality—how local interactions can control global development. How does a cell in the big toe know where it is with respect to the whole body so that its function in form-making is switched on appropriately so that the cell can do what is required of it at its position in the toe? If the blueprint of switching is itself in the DNA, as materialist biologists would have it, then how does the toe cell know only to activate the relevant part of the blueprint? We can see that there has to be a meta plan, a meta blueprint that functions in a nonlocal way, both spatially and temporally. Somehow the micro DNA strand of one single cell has to exert influence on a vast collection of cells spread across a macro region of spatial volume and over the whole time that the embryo development takes.

In materialist theories, apart from the concept of particles, there is also the concept of force fields. The difference between the two concepts is interesting. Whereas particles are discrete, fields form a continuum—they have a wholeness. For example, if we cut a magnet that generates a magnetic field, we get two magnets with the same kind of magnetic field, not two halves of the original magnet, two monopoles. This generates the idea that perhaps the holistic field concept has some usefulness for discussing a holistic phenomenon such as morphogenesis in biology.

The field concept has been used in biology quite powerfully and in connection with morphogenesis by the theoretical biologist C.H. Waddington. Waddington had a flair for language, and he created important words in his characterization of the morphogenetic field called "chreode" which is a "canalized" pathway in an "epigenetic landscape." As an illustration, consider the motion of a ball sliding down a landscape of hills and valleys. The ball follows particular valleys; its motion downward is canalized. Similarly, the development of particular parts of an embryo is canalized toward particular end points. The canalized motion of the ball is relatively immune to perturbation because of the hills that separate it from neighboring valleys. Similarly, says Waddington, the canalized development of the embryo is also immune to small amounts of environmental perturbations. But Waddington's fields, interesting as they are as an idea, will not do for morphogenesis—they are local.

So is it the morphogenetic fields that tell the particular DNA of a cell which part of the form-making plan to activate? They can if a plan is stored in the fields themselves, which are nonlocal, said botanist Rupert Sheldrake, catching the biological world by surprise and garnering an antagonistic reaction. Suppose the DNA are just receivers (like radio receivers), rather than the generators of the information of the plan. Radio receivers can receive a signal because they resonate with the electromagnetic wave of the signal; similarly, the DNA receives the morphogenetic signal, the instructions for activation of a particular part, via morphic resonance.

Thus, Sheldrake explicitly deviates from materialist models of biology where everything is assumed to be the product of upward causation, emergent as they may be. Morphic resonance is Sheldrake's way of introducing downward causation in biology. The purposiveness exhibited in biological form-making arises from this downward causation, says Sheldrake.

Of course, since the plan is global, nonlocal, Sheldrake's morphogenetic fields also

have to be nonlocal. And here Sheldrake is departing from the philosophy of scientific or material realism, according to which nothing can exist outside of matter and its rules of locality. And Sheldrake is explicit about the nonlocality of his morphic (short for morphogenetic) fields, a nonlocality, he says, that may even be of quantum origin.

Morphic resonance is also postulated to be the basis of memory or repetition of living forms. Morphic resonance consists of influence of "like upon like," previous patterns of form on present patterns of form, reinforcing the pooled memory of the species.

In this way, Sheldrake's morphic fields are different from any other postulated in biology by virtue of his bold hypothesis of 1) downward causation and purposiveness, 2) nonlocality, and 3) morphic resonance with memory property. Indeed, with these properties of morphic fields, all of the difficulties of biological morphogenesis of materialist theories are resolved.

But Sheldrake's morphic fields have an implicit dualism. They are postulated to transcend matter, they are capable of influencing matter, but Sheldrake is silent about the source of the morphogenetic fields. Resonance phenomenon in radio needs electromagnetic wave propagation between a source and a receptor. In Sheldrake's theory, there is the receptor (the living object), there is the information being received (the morphogenetic fields), but the source is left ambiguous and implicit. Perhaps this was because Sheldrake was aware that any explicit talk of a source would be attacked as dualism. But leaving out the source of morphogenetic information is the reason that Sheldrake cannot explain how the first such field comes into being. He leaves it to "some inherent creative intelligence in mind and nature."

I will show that Sheldrake's intuition is correct and that this "intelligence" is consciousness itself, looked upon as the ground of all being. Consciousness acts on matter in conjunction with a vital body that contains the blueprints of biological forms, that is the source of morphic information. (Here I am generalizing the use, in Chinese and Indian medicine, of the vital body as the container of the blueprints of health.) And the function of morphic fields and resonance is carried out by consciousness' simultaneously choosing actuality from possibility forms of both the vital and the physical body of an organism, and yet, this process does not involve dualism. Instead, the process involves self-referential quantum measurement (see later).

In passing, let me mention one more thing. Sheldrake extends his theory of morphic fields also to nonliving things, such as crystals. In the new theory expounded here, the nonliving is excluded from the context of morphogenesis. This enables us to clearly distinguish between life and non-life. Life is where self-referential quantum measurement can take place (see Chapter 29) through which consciousness imbues vital meaning to living things. Crystal has form, but its form has no intrinsic meaning other than what we ascribe to it.

Who Programs?

Materialist biologists talk about programs of morphogenesis stored in DNA, but are stymied by the question, Who programs the DNA, the biocomputer? The only answer for the materialist is, environmental conditioning driven by competition for survival and

natural selection. Furthermore, as the philosopher Gregory Bateson pointed out a long time ago, computer learning is low level learning, it is learning by rote, memory. Computers cannot learn the context of learning. They can learn within fixed contexts, but they cannot change contexts. In other words, genetic programming may be adequate for understanding morphogenesis under ordinary circumstances, but not for situations where regulation or regeneration of forms (see later) takes place. Nor is genetic programming able to explain how a new context for morphogenesis is learned.

Another difficulty with the concept of genetic programming within strict materialist philosophy I have already mentioned, is that classical programs can never simulate nonlocal behavior. So even with genes forming a cooperative program, can we understand the nonlocality of morphogenesis with this concept?

In science within consciousness, we propose that there is a creative programmer—consciousness itself. Consciousness is creative and changes the contexts of learning in the programs of the living cell. Not only is morphogenesis explainable with this hypothesis, but so too is the evolution of new forms. And not only are morphogenesis and evolution explained, but the door is opened to understanding life itself as a manifestation of consciousness, as different from insentient matter.

For life, there has to be a new organizing principle, but it is unlikely that such organizing principles reside in matter emerging at the appropriate level of complexity. But if downward causation and purpose are phenomena of consciousness, and if consciousness is the organizing principle for life, how does consciousness intervene into the behavior of matter that make up the world of manifestation? If the world really ran by Newtonian laws, there would be no way for such intervention. Fortunately, the world is not Newtonian. Ever since the beginning of the 20th century we have been discovering the novelties of a new mechanics that originated with the study of the motion of submicroscopic objects. The matter of the world obeys this new mechanics called quantum mechanics. But quantum mechanics lacks closure, making room for consciousness to intervene in the affairs of matter. Quantum mechanics broadly interpreted within the philosophy that consciousness is the ground of all being (perennial philosophy, or monistic idealism) gives us an adequate science of becoming in the biological world.

There is one more important question—the question of meaning. Computers process symbols, but not the meaning of symbols. The meaning exists in the mind of the programmer. Computer scientists routinely assume such a psychophysical parallelism in their theories. Similarly, living functions and attributes, such as maintenance, reproduction, evolution, and form, must be carried in a separate body within consciousness. This body is traditionally called the "vital body." In Eastern medicine of both China and India, the concept of the vital body is crucial and there is ample empirical knowledge of it in those traditions.

In summary, we need a theory of biophysical parallelism—a simultaneous and parallel functioning of a vital body and a physical body. But the introduction of the vital body (and consciousness) in biology surely raises the specter of dualism. It is the solution of the problem of dualism with the help of quantum measurement theory that makes science within consciousness a viable concept for biology.

To make quantum measurement theory relevant in biology, we must postulate that self-referential quantum measurement already takes place in the living cell and is respon-

sible for the split of one consciousness and its possibilities into life and environment. This gives us a profound distinction of the living, as opposed to non-living in which quantum measurements never take place. This also opens the door for the explanation of both creative and conditioned modalities of biological evolution as in the theory of punctuated equilibrium (see Chapter 29).

Now to the problem of biophysical parallelism–the parallelly operating vital body and the physical body–introduced in the previous section. How can we avoid dualism there?

Avoiding Dualism in Biophysical Parallelism

Vitalism was rejected in biology because of its problem with interaction dualism (faced by all Cartesian types of dualism in general). If there are two separate dual bodies, what mediates their interaction? And without violating conservation laws, such as the conservation of energy? If the vital body exists in a parallel existence with the physical body in exact correspondence (in the style of psychophysical parallelism as enunciated by Leibnitz), the problem of dualism still lurks. What maintains the exact correspondence?

The solution that idealist quantum measurement theory gives us is this. Consciousness mediates the parallelism between the physical and the vital bodies. This is not dualism, because consciousness simultaneously collapses (nonlocally) the quantum possibilities of the physical and vital bodies for its self-referential experience. These quantum superpositions of possibilities already exist within consciousness, which is only choosing by recognizing a particular possibility, thus it is not "mind over matter." The simultaneous collapse of the correlated physical and vital bodies maps (that is, makes a representation of) the latter onto the former. The physical is like the hardware of the computer, and it makes software representations of the vital body meta blueprint.

This resolution of the problem of dualism requires that the vital body be a quantum body, its states describable by quantum mechanics as waves of possibility. Evidence of the quantum nature of the vital body can be found in our own experience. Although vital body talk is unfashionable in the West, it remains the basis of Eastern medicine. The movements of the vital body (vital energy) are variously known as *prana* in India, *chi* in China, and *ki* in Japan. But in each of these cultures, one always finds a complementary mode of description of the vital modes common to quantum modes of movement. For example, *chi* is supposed to have *yin* and *yang* aspects. This corresponds to particle and wave complementarity of material quantum objects. Operationally, in Chinese medicine, *chi* is supposed to move in approximately localized paths called meridians; but it is well known that there is a complementarity between finding the location of the meridian vis-à-vis its direction. This is similar to the uncertainty principle of quantum mechanics.

More telling evidence for the quantum nature of the vital body is found in the demonstration of nonlocality. There is experimental evidence that "*chi gong*" masters can nonlocally affect the vital field of plants enough to enhance or reduce the rate of biochemical reactions involved in plant growth.

It is a puzzling paradox for material realist science that the perceptions of *chi* are internal and private (and thus one can doubt their existence), in contrast to the physical,

external, public objects that we share with other people. There is an explanation in our new science of the quantum vital body along lines already discussed in Chapter 24.

Quantum objects obey the uncertainty principle—we cannot simultaneously measure both their position and velocity with utmost accuracy. In order to determine the trajectory of an object, we need to know not only where an object is now, but also where it will be a little later. In other words, both position and velocity, simultaneously. So we can never determine accurate trajectories of quantum objects.

Although the macro bodies of our environment are made of the micro quantum objects that obey the uncertainty principle, because of their grossness, the cloud of ignorance that the uncertainty principle imposes on their motion is very small, so small that it can be discounted in most situations—this is the correspondence principle. Thus, macro bodies can be attributed both approximate positions and approximate velocities and, therefore, trajectories (their possibility waves spread, but extremely sluggishly). For the physical world, we use the intermediary of the macro bodies, a macro "measurement" apparatus, to amplify the states of the micro quantum objects before we can observe them. This is the price we pay—loosing direct contact with the microcosm—so that we have a shared reality of physical objects in the macrocosm. Everybody can simultaneously see the physical macro bodies.

But vital substance is indivisible. For this substance there is no reduction to smaller and smaller bits, there is no micro out of which the macro is made. The vital world is a whole, or what physicists sometimes call an infinite medium. There are waves in this infinite medium, modes of movement that must be described as quantum possibility waves obeying a probability calculus. And we directly observe these quantum modes (*prana*, *chi*, or *ki*) without the intermediary of a macro measurement apparatus (there isn't any). But there is a price we pay for the direct experience. The observation and experience of the vital modes of movement, *chi*, are subject to the uncertainty principle. What this means is that any observation disturbs the vital object, so much so that another observation would not lead to the same experience of *chi*. Therefore, *chi* cannot ordinarily be shared by two different observers. *Chi* is private. It is experienced internally. This, finally, is the explanation of the internal and private "feel" of being alive.

Further note that the quantum picture enables us to think about the physical and the vital worlds differently than we are used to. Normally, we tend to think of both of these worlds as made of substance, something concrete. Sure, the vital substance is subtler, we cannot quantify it in the same way as we can the physical substance, but it is still a substance—or so we think. We must change our view. Even the physical world is not substance in the ordinary sense, let alone the vital world. Both physical and vital worlds remain as quantum superposition of possibilities until consciousness gives them substantiality by collapsing an actual experience.

The quantum system in the physical cell, along with macro measurement apparatuses that amplify its states (and also make a record of the actualized states upon measurement), whose states are collapsed in a correlated, parallel fashion with the states of the vital body can be said to have mapped the blueprint—the biological functions—contained in the vital body. This is similar to how we write software on computer hardware. The maps are inherited by all the cells of the body of a multicellular organism through cell division. The shared maps can solve some of the profound puzzles of biological morphogenesis.

Nonlocality in Morphogenesis

In the 17th and the 18th centuries, morphogenesis was explained by biologists with the hypothesis of preformation—the fertilized egg already contains a tiny form of what is to come later. Of course, modern embryology has proven this theory to be entirely wrong. The embryo of a highly developed organism starts as a homogeneous, structureless entity that develops in successive stages that show the evolutionary history of the organism. But the preformation theory illustrates part of the materialist predicament. In materialism, we look for a materialistic beginning for everything, all development must be contained within the reductive components and their interactions. Materialist biologists have long abandoned the simplistic theory of preformation. They now believe that the genes, the DNA of the embryo cell, contain a blueprint of the form that develops. The DNA is analogized to a computer; its components behave according to programs that contain all the necessary instructions for cell differentiation. But, as already mentioned, there is a grave problem in this kind of thinking.

The problem is this. How can local interactions among the components of the DNA give rise to such spectacular, nonlocal correlations as exhibited by morphogenesis? If we think of the DNA as a computer, a classical computer, then the problem is that a classical computer can never simulate nonlocality, as mathematically shown by the physicist Richard Feynman in 1981. But if we assume a quantum component to the computing machinery of the cell, then nonlocality is no longer a problem.

It is readily recognized that biological correlations exhibited in morphogenesis are not only correlations that persist over distances, but also over time. The distance correlations can be understood easily as the play of quantum nonlocality, but how about the correlation over time? It turns out that the correlation over time is also the play of quantum nonlocality. The name of this particular play is delayed choice (see Chapter 25).

The crucial point is that in the quantum picture, the morphogenetic forms take shape first as possibility forms. They are not manifest until a bifurcation of form occurs that necessitates choice. Such a bifurcation may involve a particular form that occurred in the past, or a brand new form. Once collapse occurs, the entire causal pathway leading to the chosen form manifests at once, as if by delayed choice. Obviously this seems teleological—future-oriented choice of form. But delayed choice is a well-known characteristic of nonlocality in quantum measurement, and it has been verified by laboratory experiments.

Evolution and Morphogenesis: A Quantum Explanation of Morphic Resonance

The lesson of the delayed choice—that possibilities can wait in limbo until consciousness chooses an actuality from among them—is crucial to understanding not only morphogenesis, but also the creative quantum leap in evolution and how evolution and morphogenesis work together to map the biological functions of the vital body onto the physical as physical forms.

I have discussed creative leaps of biological evolution in the last chapter. According to neo-Darwinian dogma, evolution is gradual. But a creative change requires many individual micro mutations at the gene level working together to make a macro mutation that gives rise to a new phenotype trait, leading to a new species. If neo-Darwinist ideas of selection on every individual mutation were at work, most mutations would be eliminated, since individually they are not beneficial. But why assume that individual mutations are selected for or against?

It is a fact that mutations, either point mutations or mutations acquired in gene recombination, are quantum in nature. They are mere superpositions of possibilities before consciousness has collapsed them.

Suppose the quantum superpositions of mutated genes wait in limbo until enough of them accumulate to give rise to a phenotype trait leading to new form. Not only are the gene mutations quantum processes, but so is the making of form, morphogenesis, that is correlated to the mutations. Both evolution (of the mutated genes) and morphogenesis of the new trait wait in limbo as superpositions of many possibilities from among which consciousness can see a pattern that is just right for mapping a function-blueprint contained in its vital body. This is similar to resonance matching. It is the quantum explanation of morphic resonance.

Why should a form that occurred in the past be chosen? The answer is, forms are conditioned as part of the developmental history of life. Initially, forms exist as degenerate multitudes of coherent superpositions, and the choice among them requires creativity and purposiveness. However, a collapse of a self-referential, quantum system conditions the system.

Thus, once a form has manifested through a creative breakthrough, the probability of its repetition increases. In biology, since all life is connected to some first living cell, conditioning propagates down the line, throughout the tree of life. This is the explanation of why certain forms repeat over and over in morphogenesis. In a sense, this is a kind of memory as proposed by Sheldrake, and its manifestation does involve nonlocality, but the mechanism is quantum. In other words, we have arrived at all the virtues of Sheldrake's theory of morphic resonance without the implicit dualism.

Regulation and Regeneration

In the 1890s, the embryologist Hans Driesch discovered that if we destroy half of the young embryo of a sea-urchin, it is able to recover from the loss and develop into a complete sea-urchin (not half), albeit a small one. This phenomenon is now called regulation.

The prevalent theory in Driesch's time was that the early embryo is like a mosaic of independently developing parts, according to which the severed sea urchin would have grown into a half sea urchin. His experiment persuaded Driesch to give up materialist models altogether and opt for the idea of entelechy—a non-material causal factor of Aristotelian vintage that guided a living system holistically. Unfortunately, Driesch's thinking was dualistic, and was easily rejected by the scientific establishment for that reason.

In the present theory, we have quantum possibility forms that have nonlocally corre-

lated wholeness, but they are possibilities within consciousness, not separate and dualistic. The present theory, therefore, is able to explain why the body is able to mend certain harmful stimuli if early enough in development. If the stimuli catch the system still in the possibility domain, the system is able to work around the damage with an alternative pathway. But at later stages, when part of the causal pathway has been manifestly laid out by the collapse of the wave function, this accommodation will be difficult. This is what is found experimentally.

A similar phenomenon is regeneration. A flatworm can be severed into many pieces, but each piece can regenerate and grow into a new flatworm. Similarly, a hydra can grow back its tentacles. Even we humans have some leftover regenerative power—broken bones and severed nerves can heal. And of course, a plant has the most spectacular regenerative power; we can take a cutting from a plant and grow a whole new plant from it. What is the quantum explanation of this—or is there any?

Regeneration is quite different from regulation. Notice that in regeneration, the parts are independent of one another, they are just conglomerates of cells without any holistic function. In this case, the quantum (and the classical machinery required for amplification) of each severed part are complete by themselves and can grow by themselves. Of course, the vital body is always available with its functions and blueprints to guide the way.

Quantum Healing

Sheldrake's idea of meta-plans (the morphic fields) of functions and blueprints for the physical body forms has revived interest in Eastern medicine, a tradition according to which the vital body, not the physical, holds the blueprints of health. Recently, many cases of rapid and discontinuous healing have been found for which a quantum explanation has been proposed by the physician Deepak Chopra. The present theory of biophysical parallelism clarifies how a quantum healing mechanism may work.

What is disease? So far as the conditioned maps of the body form work properly, we are healthy. But due to the ongoing interactions with the environment, a defect may develop. The existing pathways of body functioning may misinterpret the defect and further exacerbate the problem. An example of this can be found in coronary artery clogging.

How does quantum healing work? Since the blueprints are available in the vital body, with intention and imaginative, creative efforts a patient may be able to use these blueprints to make new pathways of body functioning leading to healing. (For example, for coronary artery clogging, such healing effort leads to many small arteries' supplying blood to the heart.)

The proponents of Eastern medicinal systems also suggest another possibility. The vital body meta plans themselves may develop faults due to conditioned patterns of propensities. Hence the emphasis in Eastern medicine for healing at the vital body level as well. The reintroduction of the vital body in biology is thus paving the way for an integration of Eastern and Western medicine.

Bibliography

Chopra, D. *Quantum Healing*. NY: Bantam-Doubleday, 1990.

Goswami, A. "A Quantum Explanation of Sheldrake's Morphic Resonance." In H.P. Duerr and F. T. Oswald (eds.) *Rupert Sheldrake in der Diskussion*. Bern, Germany: Schertz-Verlag, 1998.

Sheldrake, R. *A New Science of Life*. LA: Tarcher, 1981.

Part SEVEN

OUTLOOK

CHAPTER 31

Creativity in Biological Systems

According to many researchers, the neo-Darwinist paradigm of biology leaves many unanswered questions when it tries to address the many anomalies of experimental data. Part of the problem of neo-Darwinism arises from the use of a material realist ontology—that matter is the ground of being. With such an ontology, it is difficult, if not impossible, to account for the many phenomena of biology that seem to call for downward causation, causal efficacy emanating from higher levels of the biological hierarchy acting on lower levels.

In the last two chapters, I have shown how an idealist, consciousness-based ontology—where consciousness is the ground of being—working in the context of quantum measurement theory applied to the living cell, can be used to rescue neo-Darwinism from its many anomalies. In the quantum approach, gene mutations are regarded as quantum processes of sufficient ambiguity that propagate as coherent superpositions of possibilities. The possibilities are amplified by the cellular mechanisms (acting as measurement-aid apparatuses) to the macro level, but cannot be collapsed into actualities by these mechanisms because a quantum measurement requires the self-referential action of consciousness. The wave functions collapse and the genetic material becomes fixed in one configuration only when consciousness sees a meaningful pattern emerge that merits phenotypical expression. Note that the operation of consciousness here involves cellular epigenetic processes that, while correlated with the genome (all the genes contained in a single set of chromosomes), have outcomes not comprehensible or predicted by genetic information alone. The purpose of the present chapter is to show how this approach may explain some of the other anomalies previously referred to: directed mutations, which are beneficial mutations that occur at rates significantly higher than background rates, and phenomenon of phenocopies, in which

A. Goswami, *The Physicists' View of Nature*
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a developmental anomaly becomes fixed as a genetic mutation. Both of these phenomena, no doubt, consist of controversial data, but if accepted as genuine anomalies, they raise doubt as to the universality of the neo-Darwinian model of random mutation of the genotype followed by selection of the phenotype as the primary mechanism of evolution. These data squarely raise the issue of whether an organism can respond to the environment in ways more direct than mutation/selection, and in some sense cause its own evolution.

Interest in directed mutation was revived by the biologist John Cairns and his collaborators. Certain mutations in bacteria seem to occur at much higher rates when the mutant phenotype has clear selective advantages. Other research indicates that directed mutation is not limited to a certain class of mutations or to prokaryotes. At the same time, it is now becoming clear that most, if not all, genomic changes–including recombination, transposition, and various aspects of DNA repair–are epigenetic functions and, therefore, fall logically within the realm of cellular conscious choice. These phenomena clash squarely with the neo-Darwinian bias that all mutations and related genetic changes must be random.

The other controversial phenomena that I will consider in this chapter is that of phenocopies, a term coined by the biologist R.B. Goldschmidt to describe genetic mutations that follow phenotypic changes produced by the environment. Goldschmidt found that if Drosophila (a kind of fruit fly) embryos at a certain developmental stage are exposed for brief periods to elevated temperature, ether, X-rays, or other factors that affect development, then the phenotype of the organism may be altered in ways that mimic or copy the kind of changes produced by gene mutations. In some cases, these alterations are heritable, indicating that they are accompanied by mutations, hence the term phenocopy. This phenomenon is contrary to the fundamental doctrine called the Weismann doctrine, which denies the inheritance of acquired characteristics (Lamarckism). Some biologists regard phenocopies as conclusive evidence that there are epigenetic mechanisms that contribute to evolution.

There is also some evidence of creative behavior (instability, change to new context of living) in the evolution of single cells that necessitates the assumption of epigenetic processes.

Can quantum theory, under the aegis of the idealist interpretation, provide new insights for the phenomena of directed mutation and phenocopies, while at the same time giving us a new context for studying the connection between epigenetic mechanisms and evolution? In a paper published in collaboration with biologist Dennis Todd, I showed that the answer is yes. This chapter is largely adapted from that paper.

Directed Mutation

The phenomenon of directed mutation was reemphasized by Cairns et al, and was studied in detail by biologist Barry Hall. Certain mutations in bacteria seem to occur as a specific response to immediate needs of the organism. In the experiments of Cairns et al, strains of E. coli that are unable to utilize lactose (hence termed Lac-) were plated on agar plates containing lactose as the only carbon source. Clearly such an environment was

sharply selective for Lac+ cells (cells that can digest lactose). Indeed, Lac+ cells were found to grow within forty-eight hours, indicating that they resulted from spontaneous mutations in the growing (Lac-) culture before plating. But surprisingly, as the bacteria starved and entered stationary (no-growth) phase, mutations continued to occur despite the absence of cellular reproduction; Lac+ revertants continued to accumulate. Revertants did not accumulate in the absence of lactose. The shape of the distribution of the mutants clearly indicated that some mutations took place spontaneously during the growth phase, but others during the stationary phase. It is these latter mutations that are called directed mutations.

In their seminal paper, Cairns et al declared, "We describe here experiments and some circumstantial evidence suggesting that bacteria can choose which mutations they should produce." This clashes squarely with the neo-Darwinian bias that all mutations must be random. The idea of directed mutation suggests that, at least on occasion, conscious choice may play a direct role in evolution!

Modern biology, under the influence of molecular biology, is based on the materialist ontology that everything is made of matter. In such an ontology, it is impossible to attribute causal efficacy to an organism. It is impossible to support the view that an organism can choose what mutation it is going to manifest. Thus, the response to the work of Cairns and his collaborators has either been denial—there must be some errors in the analysis of the data—or a search for a trial-and-error molecular mechanism for the process that would leave choice out of the picture.

But other researchers, especially Barry Hall, have verified directed mutation. In particular, Hall showed that even multiple, specifically double mutations can be directed. Hall worked with a strain of E. coli that can use the sugar salicin only after two mutations, one of which is extremely rare in growing cells. When he plated this strain of bacteria on salicin, Sal+ revertants appeared in twelve days, indicating a frequency of mutation that is orders of magnitude greater than the frequency of spontaneous, independent double mutations.

Trial-and-error mechanisms also are typically ruled out by direct experimental data (see below).

A Quantum Epigenetic Model

In conventional molecular biology, the actions of a living cell are seen as those of a determined machine. Proteins carry out the functions of the cell. For bacteria, this consists basically of metabolic activities. DNA provides the blueprint for making proteins as needed. When nutrients are available, bacteria grow, replicate their DNA, and fission into daughter cells. Errors that arise during DNA replication may be transmitted as heritable mutations. When starved, bacteria do not grow or replicate their DNA, but go into a "stationary" phase. Conventional theory would predict that mutations should not arise when bacteria are in stationary phase, the very circumstance in which directed mutations appear.

In experiments of Cairns and other researchers, bacteria are plated on a medium containing a carbon source that they cannot utilize, but that is within their capacity to

digest if one of their genes goes through a one-step mutation and builds a modified protein. The bacteria go into stationary phase and cease reproducing, but they are not necessarily quiescent. Genes are expressed, proteins are made, and there are some limited repair activities that may still go on. However, the repair may be slow, so some errors may persist in a newly synthesized DNA strand. When expressed, the errors may produce the useful protein, in which case the cell gets food, grows, and reproduces. The modified DNA has now gained permanent entry in the population. This is one model due to the biologist Frank Stahl of how conventional theory tries to accommodate directed mutation, but other conventional models are sufficiently similar so I will use this as a basis of comparison with the quantum model.

The fundamental difference that the quantum model brings is the inclusion of consciousness. The tangled hierarchy of the cellular apparatus of life implies the expression of consciousness, and although the expression of consciousness in a bacterium may be quite limited compared with that in a human, consciousness exerts its influence on quantum measurement as described above.

Todd and I propose that there is a cellular quantum system, and that the macro molecules of the cell, the proteins and the nucleic acids, are measurement-aid apparatuses that amplify the states of the quantum system. The states of the quantum system are coherent superpositions of possibilities, and consciousness chooses and self-referentially collapses one of the possibilities into actuality. Thus, a certain amount of choice and creativity is available even to the one-celled organism.

There is, however, conditioning to consider. Because of measurement feedback, self-referential quantum systems develop conditioning. Gradually, the conditioned responses gain greater probability weights. Since all living cells can be traced back to a single progenitor, for living systems the conditioning approaches 100%. This is the reason that the normal behavior of cells fits the materialist machine model. However, under special situations, the available creativity may be tapped. The Nobel laureate biologist Barbara MacLintock used to insist that we need to know "how the cell recognizes stress and reorganizes the entire genome in [creative] response." We believe that this is what is happening in the case of directed mutation.

In the quantum epigenetic model, a novel environmental stimulus (unlearned stimulus), such as lactose that a bacterium has never digested, excites the epigenetic quantum system in a coherent superposition that includes the new lactose-utilizing (as well as the old Lac-) response. Once again, the nutritional stress is the condition under which the creative response arises. The existing proteins are unable to amplify the state; there is no food to complete the old chain of events. Quantum effects may lead to a mutation consisting of a coherent superposition that contains a novel nucleic acid sequence. Recent work suggests that the mutation may involve conjugal replication and transfer. Eventually a phenotypic response is expressed, a lactose-digesting protein is produced in potentia, consciousness recognizes and chooses the novel nucleic acid sequence, and collapse of the wave function occurs, leading to the production of actual proteins necessary for survival. The presence of lactose is vital; mere starvation would not collapse the chain of potential events that produced the new protein, because the new potential-protein would not be recognized as suitable by consciousness.

So we are proposing that mutation may be a property of the conscious cell. When the

existing proteins are inadequate for survival, if the new food offered is within the creative limits of the quantum system and its measurement apparatuses, consciousness can choose a new course for survival.

It should be clear that there is no violation of the central dogma of molecular biology; there is no direct transfer of information from proteins to DNA. However, the process does have a Lamarckian hue to it since the environment is affecting mutation via an epigenetic mechanism. This brings us to the question, Is the epigenetic quantum process really necessary, or can we explain the mechanism as quantum processes at the level of the genes?

It is possible to make a model of directed mutation without postulating a cellular epigenetic quantum system. Suppose there is, prior to selection, a gene mutation occurring as an uncollapsed coherent superposition of possible states that include the allele necessary for survival, e.g., on Lac+. Selection may act as a trigger for consciousness to collapse the wave function into the requisite form. If the biologist P. L. Foster is right in asserting that "the evidence suggests the role of selection in the mutational process is not to 'direct' the process, but to define success," then this genetic quantum model may be the correct one. However, in that case, it seems reasonable to expect that there would be accompanying neutral mutations as well, which does not seem to be the case.

Foster thinks that there must be some sort of a trial-and-error mechanism that makes direct mutation possible. The quantum theory proposed here suggests that the trial-and-error mechanism is not based on blind chance, but that consciousness is involved. There is trial-and-error in potentia (which in the language of creativity theory is called unconscious processing), and there is also conscious choice. Evidence in favor of conscious choice may be found in the cases of double mutations without any reported intermediates. The model of quantum creativity readily accounts for the accumulation of uncollapsed coherent superpositions and their apparently single-step collapse.

As Foster correctly points out, in directed mutation, we are finding that "a nondividing cell is, potentially, multiphenotypic, a characteristic previously thought to be true of the population, not the individual." A haploid cell (an organism with a single set of unpaired chromosomes) can be multiphenotypic only in potentia, by virtue of creative possibilities in the coherent superpositions of its quantum system. We should note that, as a quantum process, directed mutation is a creative phenomenon and as such may not be as predictable as conditioned behavior. In other words, there would occasionally be failures on the part of the bacteria to break through to a solution before, for example, they starve to death. This may explain why other researchers, such as Mittler and Lenski, report only normal mutation rates in some of their experiments.

One might ask why directed mutation is not more common. That is, why few external environmental stimuli produce adaptive genetic changes. The answer is vitally important to understanding the role of quantum systems. It is conditioning. Ordinary environmental stimuli are learned stimuli for which the response of the quantum system is conditioned, that is, the response occurs with increased probability. In that case, the interaction of the genes and the epigenetic quantum system also proceeds along conditioned (canalized) pathways and classical, determined behavior prevails. Obviously, under such situations, the quantum (creative) action is suppressed and all the behavior can be explained without invoking the epigenetic quantum mechanism.

Explaining Phenocopies Within Neo-Darwinism

Phenocopies are somatic abnormalities, induced by environmental factors, that resemble changes usually attributed to gene mutations. The neo-Darwinian approach to phenocopies is a modified version of an old theory of genetic selection. As the environment produces somatic modifications–the phenocopies–coincident gene mutations are supposed to produce the same phenotypes. If adaptive, these phenotypes would obviously be favored by natural selection. Here the criticism is the same as that against Darwinian evolution. If most mutations are selected against, it is hard to see how a series of mutations necessary to produce the genes that are needed for the required modification of the phenotype can occur. Surely, intermediate states would have no selective advantage, and thus would be eliminated. However, we can argue that if the quantum idealist perspective is adopted, genetic changes will propagate as uncollapsed coherent superpositions until the phenotypic expression corresponding to the phenocopies has occurred, precipitated by an act of creativity by consciousness. Essentially, the phenocopies here act as triggers for consciousness to creatively collapse the (previously) uncollapsed wave functions.

Note that in this way the Weismann barrier is not violated, nor is the central dogma of molecular biology, but the restrictions imposed by both are bypassed. However, this theory still leaves us unsatisfied, since no causal connection is made between the environmentally induced somatic modification and the subsequent genetic assimilation. Furthermore, the theory is not experimentally verifiable because it is impossible to predict *a priori* if coincident mutations will be creatively precipitated.

The biologist Conrad Waddington used the idea of modifier genes to incorporate some causal connection between the effect of the environment, namely, the production of phenocopies, and the subsequent genetic assimilation. In a population heterogeneous in modifier alleles for an adaptive response, certain modifier alleles will be selected. The result should initially be an intensification of the phenocopy somatic response. Gradually (or simultaneously) a regulation of the intensity of the response will take place so that the degree of response does not change as long as the intensity of the environmental stimulus remains within a certain range. Waddington calls this the "canalization" of the response. Finally, the response will occur even in the absence of environmental stimulus; at this stage one can say that genetic assimilation has occurred.

There is some experimental support for Waddington's idea of modifier genes. However, more recent experiments by the biologist Mae-Wan Ho and her collaborators suggest an alternative explanation (while not completely ruling out Waddington's theory) in terms of cytoplasmic inheritance.

Before going into the details of Ho's experiment, it would be useful to discuss in more detail the epigenetic manner of thinking about phenocopies and how the quantum can be invoked in the epigenetic approach.

The Epigenetic Approach and the Quantum Theory of Phenocopies

The neo-Darwinist approach to development is to divide the organism into a heredi-

tary part that programs for all forms and behavior, and a non-hereditary part whose function is nothing but to respond to the instructions of the hereditary part. Especially with the discovery of regulatory genes, the assumption is widespread that "a theory of development would effectively enable one to compute the adult organism from the genetic information in the egg." A concomitant assumption is that the phenotype can be completely reduced to the genotype.

The biologist Brian Goodwin gives several exceptions to these assumptions of neo-Darwinists. An example is what is called the homeotic mutations of fruit flies—mutations that have the effect of replacing certain appendages normally appearing in certain segments with appendages that normally belong to other segments. A mutation called aristapedia, for example, results in the appearance of a leg where normally there is a part of the antenna. However, it is commonplace to find that a fruitfly carrying aristapedia will have a normal antenna on one side of the body, while a leg appears on the other side. Clearly, this indicates that there is no one-to-one correspondence between genotype and phenotype.

Phenocopies are a problem to neo-Darwinist attitudes because here is a case where the environment (external stimulus) produces the same phenotype changes that can be produced by mutated genes (internal stimulus). Says Goodwin:

> A mutation would be equivalent to a specific change in a program such as the systematic replacement of one letter or number or operating symbol by another. That such a "perturbation" would result in a specific disturbance in the computer output is clear enough; but the probability that this specific alteration of output would be mimicked or copied by some general disturbance to the computer, such as transient overheating or temporarily reduced power, is vanishingly small, unlike the situation observed in phenocopies of homeotic mutations.

Goodwin concludes that the phenotype could not be said to be causally related to genetic programs in any straightforward way, such as the way that structural genes can be said to be causally responsible for making proteins. Instead, he argues that all that can be said is that genes affect a "self-organizing process that has a limited repertoire of possible responses." Environmental stimuli evoke the same responses from these self-organizing processes, explaining the occurrence of phenocopies.

Goodwin attributes this self-organizing process with a limited repertoire of responses to morphogenetic fields, or epigenetic mechanisms "that regulate expressions of genetic potentialities" in contrast to genetic mechanisms "that maintain structural information." Although Todd and I support the idea of epigenetic mechanism, we think that self-referential quantum system plus measurement-aid apparatus, now assumed to have a cellular as well as a genetic component, is a more succinct model of the origin of these self-organizing epigenetic processes.

We propose the following model for phenocopies. There is both a quantum system in the cell and proteins that can be modified by environmental stimuli. The protein modifications become the phenocopies. The interaction of the environmentally affected cellular quantum system with the genetic apparatus leads to gene mutation, which itself is a quantum process. The mutated genes remain as uncollapsed, coherent superpositions while

such mutations accumulate in possibility. They are amplified by the measurement apparatuses of the protein-producing machinery but still remain in possibility. Eventually, when there is a realization of the desired phenotypical expression (the phenocopy) in a particular organism, consciousness recognizes it and collapses the whole chain from the quantum system to the genotype to the phenotype. At this stage genetic assimilation has taken place and phenocopies occur even without direct environmental stimulus.

If this model of Goodwin's self-organization process is correct, then the wave functions resulting from the quantum interaction between the environmentally stimulated quantum system and the genes leading to mutations may remain uncollapsed through several generations. This will require, as Ho asserted, cytoplasmic inheritance as well as normal genetic inheritance. There should also be a steady increase of the phenocopy response in successive generations, even without artificial selective breeding.

Finally, the experiment by Ho et al supports our model. Ho investigated the same bithorax phenocopy investigated by Waddington, but without any selective breeding. Indeed generations of ether treatment were found to increase phenocopy frequency. Ho also found direct evidence for cytoplasmic inheritance. After the first six generations of ether treatment, embryos resulting from a cross between treated females and control (untreated) males showed similar increased tendency to phenocopy as the long-term treated line. However, the cross between untreated females and treated males gave embryos with no more response than controls.

Rubin's Experiments: Heterogeneity and Creativity

Todd and I are then suggesting a generalized creativity model for evolutionary and developmental changes where quantum processes in gene mutation are involved, and where epigenetic quantum processes play a major role. The biologist Harry Rubin and collaborators at the University of California at Berkeley have been carrying out a series of experiments that indicate further support of creativity in the cell.

Rubin works mostly with cancer cells. He takes them out of tissue and grows them in a monolayer culture. What he finds is that when freed from homeostatic influences of the tissue and the organism, these cells exhibit much original behavior that he labels as "heterogeneity," emphasizing the difference from the usual conditioned homogeneity, following an idea of physicist Walter Elsasser. But Rubin's cells may be indicating much more than heterogeneity.

Rubin's experiments indicate many aspects of creativity. His cells are inherently unstable, there is definite evidence that the cells make creative choices to change the context of their growth and instability, and creative growth is followed by homeostasis. Rubin's experiments also demonstrate that the creative process involved is basically epigenetic although it "may be stabilized by genetic changes," as theorized in this paper.

Thus, it is only because of conditioning that we do not normally see the quantum connection of the cell, which may be both genetic and epigenetic; we need very special situations such as in the experiments discussed above.

Bibliography

Cairns, J., Overbaugh, J., and Miller, J.H. "The Origin of Mutants," *Nature*, vol. 335, pp. 142-145, 1988.

Elsasser, W.M. *Reflections on a Theory of Organisms*. Frelighsburgh, Quebec, Canada: Edisions Orbit Publishing, 1987.

Foster, P.L. "Directed Mutation: Between Unicorns and Goats," *Journal of Bacteriology*, vol. 174, pp. 1711-1716, 1992.

Goodwin, B. "A Relational or Field Theory of Reproduction an Its Evolutionary Implications," in *Beyond Neo-Darwinism: An Introduction to the New Evolutionary Paradigm*, M. W. Ho and P. Saunders (ed.), pp. 219-242. London: Academic Press, 1984.

Goswami, A., and Todd, D. "Is There Conscious Choice in Directed Mutation, Phenocopies and Related Phenomena? An Answer Based on Quantum Measurement Theory," *Integrative Physiological and Behavioral Science*, vol. 32, pp. 132-142, 1997.

Hall, B.G. "Adaptive Evolution that Requires Multiple Spontaneous Mutations: Mutations Involving an Insertion Sequence," *Genetics*, vol. 120, pp. 887-897, 1988.

Hall, B.G. "Spontaneous Point Mutations that Occur More Often When They Are Advantageous Than When They Are Neutral," *Genetics*, vol. 126, pp. 5-16, 1990.

Hall, B.G. "Adaptive Evolution That Requires Multiple Spontaneous Mutations: Mutations Involving Base Substitutions," *Proceedings of National Academy of Science*, vol. 88, pp. 5882-5886, 1991.

Ho, M.W. "Environment and Heredity in Development and Evolution," in *Beyond Neo-Darwinism: An Introduction to the New Evolutionary Paradigm*, M.W. Ho and P. Saunders (ed.) London: Academic Press, pp. 267-290, 1984.

Ho, M.W., *The Rainbow and the Worm: The Physics of Organisms*. Singapore: World Publishing, 1994.

Ho, M.W., Tucker, C., Keeley, D., and Saunders, P. "Effects of Successive Generations of Ether Treatment on Penetrance and Expression of the Bithorax Phenocopy in Drosophila Melanogaster," *Journal of Experimental Zoology*, vol. 225, pp. 357-368, 1983.

Rubin, H. "The Significance of Biological Heterogeneity," *Cancer and Metastasis Reviews*, vol. 9, pp. 1-20, 1990.

CHAPTER 32

Consciousness and Evolution

Most scientists look at evolution from a materialist point of view. Now that we have found plenty of evidence for, and good theory to corroborate, the idea that consciousness intervenes in biological evolution, we must recognize that the materialist ideas that matter evolves so that life can emerge, and life evolves so that mind and consciousness can emerge are themselves wrong. How should we look at evolution from the point of view of a consciousness-based science?

Two philosophers of recent times, Arthur Young and Sri Aurobindo (the philosopher Ken Wilber has also propounded a view similar to Aurobindo's), have emphasized a very different view of evolution. This is the idea that descent, or involution of consciousness, must occur before ascent, or evolution, can take place.

Let's discuss Young's idea first. Young stays closer to the materialist model in that both involution and evolution are seen in the progression of matter itself (although implicitly, consciousness is present from the beginning). Young says that reality begins with photons of light, pure quantum objects with total freedom. Gradually, structures that are bound and less free begin to form: other elementary particles, atoms, molecules, and complex molecules. This is the involution of reality—from total freedom to the maximum bondage of macro matter in aggregates of molecules. But then a turning-about happens. Some complex molecules form a living cell, and the return journey toward freedom begins—evolution. Single cells form aggregates, and vegetation is created. Then animals with locomo-

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tion evolve, increasing freedom. Finally, the human being with creativity evolves, and the possibility emerges to become totally free once again. This is called Young's arc (Figure 32.1).

According to Aurobindo's cosmology, or world picture, for the sake of play the transcendent consciousness throws itself downward and outward into manifest levels that are grosser and grosser. As consciousness descends, it also forgets itself. Thus, each descending level corresponds to one of increasing forgetfulness and decreasing freedom. Also at each level, the previous, subtler level is forgotten, relegated to the unconscious. At the lowest level, all is unconscious. This is the material level. This is called involution because all the higher levels are potential in matter, ready to unfold.

Once involution is complete, evolution begins. But the evolution of matter in this picture is seen in a different context from that of the materialists. Thus, life does not emerge from matter, from material properties and interactions alone—a higher level can never come from a lower one. Life emerges at a certain level of complexity of matter because it was already potential. Mind emerges, likewise, from a certain complexity of life because it was already potential (Figure 32.2).

One must not think that all these levels involve dualism. All this separation in consciousness is illusory, a mere appearance. Consciousness forgets itself for the sake of play—it pretends to forget, so to speak.

This picture is largely taken from esoteric traditions such as the Hindu Vedanta and the Jewish Kabbala. In a certain way, it makes sense and is more satisfying than the absurd materialist emergentism. What it lacks, however, is details. How does forgetfulness come about? How does what is potential become actual?

Idealist science, as already indicated, gives a satisfactory answer to the first question. Manifestation occurs via a tangled hierarchy, causing illusory separateness, which, in turn, causes temporary forgetfulness. Thus, at the mental level, the mind's subtle substance presents to consciousness possibility structures that contain mind stuff—meaning. But consciousness and its mental possibilities remain an unseparated whole. When consciousness self-referentially collapses the possibilities into actuality, this creates apparent separation between subject and object, and there is forgetfulness of the unity. Similarly, at the life-level, consciousness experiences the (apparent) separation between life and environ-

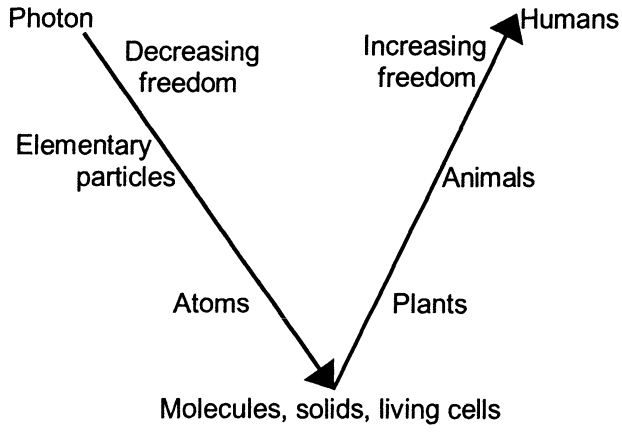

Figure 32.1
Young's arc.

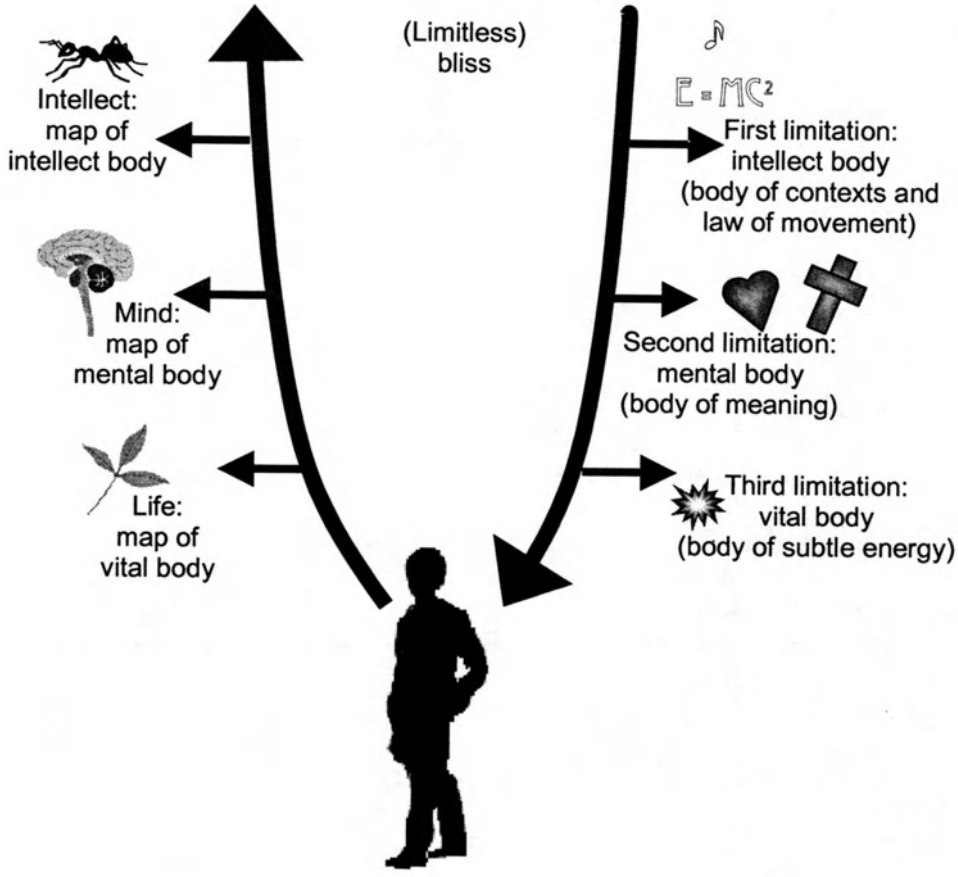

Figure 32.2
Involution and Evolution of Consciousness.

ment, a grosser separation, and again there is forgetfulness. However, no actual collapse or separation takes place until the physical body arrives on the scene. This is because manifestation requires tangled hierarchical quantum measurement, and only matter with its micro-macro division can produce such tangled hierarchical measurement apparatuses.

How does what is potential in matter become actual? At a certain level of complexity of physical matter arrived at via unconscious processing, tangled hierarchy and quantum measurement come into play. Now consciousness can supervene in matter via self-referential collapse of the quantum possibility wave. And consciousness remembers the previous level, the level of life. It employs matter, as we employ a computer, to program life in the living cell and its conglomerates, using the vital forms as guides (notice the similarity here with Sheldrake's idea of morphogenetic fields guiding the development of adult form from an embryo). Evolution and morphogenesis of life now can take place. Eventually, the conglomerate of cells known as the brain evolves so that mind can be programmed, can be embodied.

The Theme Body or the Body of Intuitive Knowledge (Also Called the Intellect)

On closer examination of Figure 32.2, you will find that in Aurobindo's picture the involution of consciousness involves a "higher mental body" called the intellect even before the involution to the mental level. What is this about?

Do we have a body in our psyche that is subtler than the mind? The mathematician Roger Penrose, in his book *The Emperor's new Mind*, gives us a proof of a sort of compartment of consciousness subtler than the mind. His proof involves Gödel's theorem—every sufficiently elaborate mathematical system always contains a proposition that it cannot prove. Although the mathematician sees the validity of the proposition intuitively, he or she has no way of reaching it through logic, through the use of the mathematical system of algorithms at hand. How do mathematicians do it then? Because they, and inferentially all of us, have a body higher or subtler than the mind. This is the body traditionally called the intellect (it can also be seen as the body of intuitive knowledge). However, I also call it the "theme body." Why?

What mathematicians discover are mathematical themes, metamathematics, laws that govern mathematics. Similarly, physicists discover the laws that govern the movement of physical bodies. These laws are not written in matter, they transcend matter. Similarly, artists discover and play with the laws of the movement of meaning—the mind. Practitioners of Eastern medicine discover and play with the laws of movement of vital energy. The laws of all these bodies are the themes that comprise the intellect. Hence the name theme body.

So the objects of the theme body are not thought, but contexts of thought. The experimental proof of the theme body is the existence of two kinds of creativity. As discussed in Chapter 23, creativity involves the invention of new meaning—situational creativity. But there is also a higher creativity that consists of the discovery of a new context for the exploration of new meanings—fundamental creativity. Fundamental creativity, in this way, involves quantum leaps of the mind to the theme body.

The recognition of the theme body solves a deep question that has puzzled many physicists—why are physical laws mathematical? If matter is the basis of all things, if matter is all that exists, then laws of matter should derive from material interactions themselves. So why are these laws expressible in terms of mathematics? Is mathematics prior to material movement then? It has to be, as are the laws of physics. They come from our theme body.

What we call abstract thinking is possible because, with every discovery of a theme, we map the theme body in the mind. The neocortex enables us to map the new thinking onto the physical. Once these maps or thought representations are available, any mind can use them as contexts of thinking—abstract thinking.

Science and the Great Chain of Being

There is a hierarchy of being in manifest reality called the great chain of being. We can

recognize easily these levels of being in our language: insentient matter, life, mind, soul, and spirit. They form the great chain of being because they exhibit a progression in the manifest expressions of consciousness. The discovery of the contexts of movement in each of these levels of being is the objective of science in its most general form.

But in materialist science, we have missed this progression. We have missed it because we have failed to acknowledge consciousness as real. We have been blind to the idea that evolution is the movement of consciousness toward the exploration of greater and greater meaning. To be sure, intuitively we have divided science into compartments that roughly follow at least the lower rungs of the great ladder of being. Thus we have science of insentient matter in physics and chemistry. Then we have science of life–biology, and science of mind–psychology.

But the materialist philosophy of Newtonian physics dominates all the branches of science. Partly, the reason is historical. Newton developed his physics on the basis of two great ideas: First, objects have a natural state of motion called inertia–the tendency to stay at rest or to move with constant speed in a straight line. Second, changes in this state of inertia are brought about by forces. Darwin found the analog of the concept of inertia in biology–homeostasis. His analog of force for biological change was natural selection. Thus, biology was founded as Newtonian biology and that umbilical cord was never severed, in spite of the many inconsistencies of the Darwinian paradigm. The same thing happened in psychology. Freud formulated the concept of the ego in analogy with Newtonian inertia, and the analogy of force was the psychological drive from the unconscious. Behaviorists imposed the whole thrust of Newtonian determinism on our psyche.

The materialist domain of reality is reductionistic. Trying to study matter with ideas of holism–recent ecological models notwithstanding–has not been successful. In reductionistic science, it makes sense to expect to explain everything on the basis of the physics of elementary particles. But does a total adherence to reductionism make sense in the life sciences? Can we explain all of biology in terms of genes?

The domination of the life sciences by classical physics also creates the unnatural goal of objectivity, fostering the belief that consciousness as a causal agency must be kept out of even the life sciences at all costs.

But the current paradigm of physics is quantum physics, which exhibits many paradoxes when the conceptual lens of materialist philosophy is used to understand it. These paradoxes are resolved when consciousness is allowed to enter physics via quantum measurement. This has led to the formulation of the science within consciousness explicated here. Its basis is the new physics–quantum mechanics interpreted in accord with the idealist measurement theory in which consciousness collapses the quantum possibility waves.

In this book, we finally see holism correctly applied in science because we recognize the vital, mental, and the theme worlds that consciousness maps in matter. Purpose, meaning, and the process of the mapping cannot be reduced to the physics of elementary particles. Only the physical is *res extensa*, body with extension, only the physical is reducible to elementary particles. The vital, mental, and theme substances are inherently whole. Even the maps of their states onto the physical retain a wholeness that denies complete reduction.

A true holistic, idealist biology must deal not only with the holistic aspects of the maps of life in matter, but also with the process of map-making. Thus, it must investigate

the vital domain of reality. Such investigations have been carried out in the past in the East, where they have greatly influenced the practice of medicine. The new biology should be instrumental in bridging Western and Eastern medicine. Western medicine is based on strict materialism—life is chemistry. Disease is chemistry gone awry and is something to be fixed by adding chemicals from the outside. In contrast, Eastern medicine is aware of the existence of the vital body, which carries the originals of the physical body's maps of well-being. In the Eastern view, if disease is faulty chemistry of the representations, since the originals are available, then we can make new maps. The Eastern view also acknowledges the possibility that the originals may have developed faulty patterns of habit, and need to be corrected via creative intervention. In both pathways to healing, we must regain some experiential, conscious relationship with our vital bodies.

Can the two views be integrated? This won't be easy and will keep idealist scientists busy for decades. Fortunately, such integrational work has already begun.

Similarly, the new idealist psychology will study not only the maps of the mind in matter, but also the mental world that the maps represent. The study of nonlocal psychology will become mainstream, and transpersonal psychology will work hand-in-hand with the new cognitive science that will undertake the study of the processes of consciousness involved in making the maps of the mental world in the physical.

In traditional science, the domain of the soul and that of spirit was left out from the beginning. They were left to religions and eventually were denigrated as mere superstition. In the new science, Jungian analytical psychology and transpersonal psychology, together with religious and spiritual traditions, will become a true science of the soul and spirit levels of our existence that will include even such far-out "Eastern" ideas as reincarnation and liberation from the bondage of ego-limitations.

One important thing about the new sciences is that they correspond to the old sciences in some well-defined limits. This correspondence principle makes possible a smooth transition between the paradigms. Thus, in the limit of complete maps and conditioned behavior, the new biology and psychology echo the old. Also, the correspondence principle assures us that we have not wasted our time in developing the materialist limit of the sciences first.

The new and the corresponding old sciences are shown in Table 32.1. Behold! The new idealist paradigm of science covers the entire great chain of being. It studies each level of being in its full context and always with consciousness as the one monistic ground of being.

Newtonian science helped breed the worldview of modernism that still dominates Western culture. In this view, the human person is an individualist and problem-solver with dominion over nature. The modernist God is a creator-God, with man as the (too often opportunistic) caretaker of His garden. When the message of Newtonian science was broadcast and it became clear that a dualist God of modernist vintage cannot be supported without contradicting the laws of science, the worldview began a shift toward a post-modernist pessimism—since all is determined by scientific laws, we are not the movers and shakers of reality that we thought we were. Perhaps we have no meaning at all. The paradoxes of quantum physics, of the mind-body problem, and of life, only exacerbated the shift away from reality to the Never-Never Land where there is no metaphysics, no ontology, no absolute values, and no responsibility.

Table 32.1
Science and the great chain of being.

CONVENTIONL SCIENCE (physical reality is primary		IDEALIST SCIENCE (consciousness is primary)
	spirit	science of the supermind
	soul	science of mapping of the theme body
psychology (behaviorism/ cognitive science)	mind	science of mapping of the mental body
biology (neo-Darwinism/ molecular biology)	body	science of mapping of the vital body
physics/chemistry (Newtonian/Einsteinian/ quantum mechanics)	matter	quantum measurement theory with consciousness as the causal agent

The new idealist paradigm of science, as developed here, should change this trend. It restores the power and meaning of the individual, which is the essence of a modernist view, without the distorted view that we dominate nature. It removes the helplessness of post-modern pessimism that obscures our responsibility. The picture of the universe that develops here is that it is a self-aware, creative universe, and that we are its co-creators. We are responsible for our environment and for the world, because we literally are the world.

How Far Evolution?

Sri Aurobindo contends that evolution does not end with humans as we are today; there may be an evolutionary future before us, an astounding future. The philosopher Pierre Teilhard de Chardin calls this future the progression toward the omega point.

In Sri Aurobindo's terminology, humans go through a series of stages depending on how far they are able to codify their world. If one is only capable of mental thinking in response to the physical world's stimuli, then Aurobindo calls it *the physical mind*. Next in his codification comes the *vital mind*–a mind capable of giving meaning to emotions–the stimuli of the vital body. Next comes the *higher mind*–the mind capable of reasoning, abstract thinking, and situational creativity, which are acting within the realm of mind itself, taking help from somebody else's fundamental creativity. The next stage is that of *illumined mind*, a mind capable of taking an occasional leap of fundamental creativity to the theme body, a mind in which creative intuition has begun to play a role. When the capacity for intuition becomes stabilized, we have the *intuitive mind*. There are two more

rarefied levels in Aurobindo's thinking, the *overmind* and the *supermind*. Below I will give a little more detail of Aurobindo's stages of evolution processed through the wisdom of the new science.

The Physical Mind

The mind puts meaning in what the brain takes in as physical stimuli, and the mapping of the meaning produces developmental software in the brain. Many people don't rise beyond this level of mental activity as adult egos. Aurobindo calls this kind of a basic mind the physical mind. It is operationally okay to get by in the affairs of the world, but such a person does not access the rich, inner life available through the other levels of the psyche. For example, a person with such a mind is capable of building a logical structure, but only when he or she can model it from the sensory world of physical objects. Someone with this kind of mind is resistant to emotions, too, because he or she cannot make a physical model of emotions.

The Vital Mind

This is the first level of mind that recognizes the extraphysical subtleties of consciousness. A person with a vital mind recognizes vital energy stimuli, in addition to physical stimuli, but gives meaning to these patterns of energy with his or her mind, at the mental level and does not engage the intuitive facility of the intellect or the theme body. Such a mind tends to get lost in the melodrama of unruly emotions, mostly felt as negative. Such a mind thrives in sensuality, pleasure, and even pain.

Most of us live alternating between a physical mind identity and a vital mind identity. In men, the physical mind is more developed than the vital; in women it is the other way around.

Still, the vital mind is very important because even at this level of identity there are occasional forays into higher levels of mental activity that convert the feeling of negativity of emotions into positive feelings, such as love and humor. Such forays are transformative.

The Higher Mind

When we learn to use our minds even at the mental level, in other words, when we can give meaning to meaning itself, we are in the higher mind. The logical structures of the higher mind, then, do not have to depend on mechanical models. In this way, a higher mind is capable of abstract thinking. A person of higher mind is also capable of examining the meaning structure of his or her constructs, and taking a quantum leap to discover new meaning–situational creativity.

In the formative history of the higher mind, as children, the people of higher mind take many creative leaps of discovery (fundamental creativity) into the intellect or theme body to discover the contexts of (abstract) thinking. But as an adult ego, a homeostasis sets in and such a mind becomes complacent with his or her logical structures based on

learned contexts. At best, they are capable of leaving a small window of exploration in fundamental creativity in a field of their expertise.

So part of the experience of the higher mind is one of what we call high intellectualism, but the intellect is frozen. For example, as emphasized by the psychiatrist Uma Krishnamurthy, in such minds the intellect is not used to transform negative emotions (such as hatred or sadness) into positive emotions (such as love or joy). In some higher minds, artists for example, the negative emotion drives the person to great heights of creativity. This is the basis of Freud's theory of creativity as a drive of libido.

So, in general, although people of the higher mind can be mentally healthy in the normal sense, capable of dealing with the environment without major mental chaos (or neurosis), they are not particularly happy.

The Illumined Mind

At the next level, forays into the intellect are taken not only for outer creativity, but for inner creativity as well, for transformative purposes. People at this level are not intellectually frozen upon reaching adulthood; they continue to explore the intellect, to discover the themes of life to a fuller and fuller extent. In this way, they discover the transformative power of unconditional love, which transforms even the most negative emotion of hate. Such beings, then, are the people who sustain our civilizations, great minds such as Henry Thoreau, Mahatma Gandhi, Eleanor Roosevelt, and Desmond Tutu. These are people who often have peak experiences of creative insight as designated by the psychologist Abraham Maslow, who described the mental health of such people as positive mental health.

Maslow's data shows that roughly 5 to 10% of all people in the world currently belong to this level of mind. The illumined mind values creative illumination and thrives in it. However, this is an intermediate stage because creative intuition is not stabilized and such a mind, although capable of acting from an inner silence, still resorts to reasoning for many day-to-day operations and relationship issues.

The Intuitive Mind

At the next level of maturation is the intuitive mind, where the ego identity shifts from the mind and becomes fully stabilized in the intellect or theme body, and the power of creative intuition guides the actions of such people. Because there is now complete mastery of vital energy, such beings display complete equanimity. Zenmasters, the great Sufi dervishes, the Hindu rishis, the mystical Kabbalists of the Judaic tradition, Christian mystics, Tibetan lamas and rinpoches, etc., typically exemplify this level of being.

Overmind

Beyond the intuitive mind, says Aurobindo, is the overmind. The identity now shifts to the bliss body, the causal realm transcending the exterior focus of the physical and the interior focus of the vital, higher, illumined, and intuitive minds. Even the mastery of

physical laws is now implicit. Miracles happen often in the proximity of such minds. Now we are speaking of a very rare sample of people, sages like Pythagoras, Jesus, Buddha, and more recently, Ramana Maharshi and Ramakrishna. Nevertheless, every one of us, according to Aurobindo, is capable of functioning at this level. Human evolution is going toward such a rarefied level of being. This is what the great Teilhard de Chardin also envisioned with his concept of the omega point.

Supermind

Aurobindo hypothesized a still higher level of evolution called the supermind, and he spent (with his collaborator, known as the Mother) the last part of his life investigating it. Supermind, crudely speaking, amounts to the descent of divinity in human flesh. At this time, there is no good evidence of anyone succeeding to live at this level.

Outlook

The perceptive reader will notice the parallel of some of Aurobindo's idea with Jung's classification of people into four groups: sensing, feeling, thinking, and intuition. Jung's classification is based on his vast experiential data collected from his therapeutic patients, and thus Jung indirectly provides evidence for the validity of Aurobindo's ideas.

So where do we go from here? The transpersonal psychologist Pierre Weil, founder of the UNIPAZ movement in Brazil, is developing a school of transformative education based upon these ideas. Unfortunately, his work is still not available in English. In the next chapter, I will expound further the task in front of us.

Bibliography

Aurobindo, S. *The Synthesis of Yoga*. Pondicherry, India: Sri Aurobindo Ashram, 1955.
Jung, C.G. *The Portable Jung*, ed. J. Campbell. NY: Viking, 1971.
Young, A. *The Reflexive Universe*. NY: Delacorte Press, 1976.

CHAPTER 33

The Challenge of Trans-Modernism

So are we past the age of modernism, even post-modernism? Hardly. Modernism, with its human-over-nature philosophy, still dominates the West—and the philosophy is still being exported to other parts of the world. The post-modern malaise and angst still dominate some of the creative elite of our society. And much of new-age thinking is still dominated by the very soft attempts to reintegrate spiritual values into science, characteristic of the deep ecology movement. And yet, with a paradigm shift from a matter-based science to consciousness-based science on the way, there is a real opportunity to enter a truly new age that transcends both modernism and post-modernism—the age of trans-modernism, transcendental modernism. But first, an explanation of terms.

Modernism, to repeat, developed from sixteenth century ideas of Francis Bacon and René Descartes. The modern human has free will, which humans can and must, according to the proponents, use to dominate nature, which is inanimate, which is devoid of free will. Post-modernism in its pessimistic version grew out of classical physics' seemingly successful demonstration that humans and nature belong on the same footing—neither humans nor nature have free will, they are all determined machines. In the optimistic version of post-modern philosophy, based on the philosophy of holism, the idea that humans and nature belong together is kept, but the idea that there is no free will is challenged. At least, there is an appearance of free will, even spirituality, emerging from the very complex interactions that play in nature. Yes, matter is the ground of being. But the behavior of matter does not have to be reductionistic. In the most optimistic version of this philosophy, holis-

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tic principles such as consciousness and even spirit, not reducible to elementary particles and their interactions, are assumed to exist at the most complex levels of nature. This version of post-modernism thus embraces a form of pantheism—God in nature. Accordingly, we should preserve and conserve nature, even worship nature. This is a thoroughly ecologically respectful worldview; indeed, it is sometimes called deep ecology.

So what is trans-modernism in this context? I call trans-modernism the worldview that is growing out of and that is based on the philosophy of monistic idealism and the developing science within consciousness. If consciousness is the ground of all being, what is our relationship with nature? As I wrote in a previous chapter, a consciousness-based metaphysics gives us the deepest ecology, since in this view we are the world, we are nature. And yet, we also have free will and creativity in a much more expressible fashion than the rest of the animate nature around us. So we also have responsibility.

The Dance of Gaia

James Lovelock and Lynn Margulis have given us the idea of a living earth, Gaia. In Greek mythology, Gaia symbolizes the living earth, and the evolution of life on earth is seen as the dance of Gaia. With a consciousness-based science, we are reviving this ancient mythology.

However, Gaia is much misunderstood. Therefore, a few more words of clarification. The earth has an inanimate component and an animate component. The distinction between the living component and the nonliving component is important. Although both are in consciousness, consciousness identifies only with the living component, only the living component has experiences of subject-object cognition. What makes the living component one planetary life, one planetary consciousness, is that, as Darwin correctly intuited long ago, all life originates from that first living cell, and is, in a way, still that living cell, vastly expanded, of course, through creative evolution.

When we look at the unity of all life on earth, all life being the representation of Gaia, then ecology takes on a new importance, doesn't it? A caterpillar is reborn as a butterfly, but the joy of its rebirth is celebrated throughout the earth's ecosystem, literally. It is important, however, to discover this unity earth consciousness directly, then only are we able to relate to our earth mother the way a child does, with love. The trans-modernist worldview is a transformative worldview. If you do not see the value of transformation, trans-modernism will pass you by. The transformation that is aborning is based on four quantum principles.

The Driving Principles of Trans-Modernism

Every new movement has a driving force. For modernism, it was the idea of investigation, a search for knowledge that would give us power—power over nature, power over poverty and misery, power over the shackles of the church. For post-modernism, it was the despair of realization that it all might be pointless, it all might be a conditioned play

of matter! For post-modern holism, it was the urge to save the earth's environment.

For trans-modernism, the driving principle is the intuition that we have much creative and spiritual potential to unfold, and if we unfold this spiritual potential, then only will we have power over our destinies. But this power must come with wisdom, and this requires spiritual transformation. Trans-modernism retains the modernistic idea of free will, but complements it with the idea of responsibility within the context of spiritual transformation. Trans-modernism similarly retains the ideas of an ecological worldview, again complementing it with the idea of transformation.

I have already written of individual transformation, the path for which is also called inner creativity. The trans-modern society will also be committed to societal transformation, and it will do this through consciousness research and education.

Of course, this is not entirely new. The idealist societies of the past were also dedicated to consciousness research and dissemination through education, but several factors always thwarted these noble efforts. For one thing, these societies undermined the material, and thus were vulnerable to materialist forces (the "barbarians" from outside). Second, there was a lack of a "scientific" attitude, and by that all I mean is an attitude of grounding all ideas on weakly objective experiential investigations and objective experiments whenever possible and as far as practicable. In the absence of such grounding, great and noble ideas such as consciousness as the ground of being became ritualized into dualistic beliefs, superstitions, and practices.

What is different now is that trans-modernism is growing out of a true integration of the spiritual and material worldviews. The motivating force behind previous idealist or spiritual cultures was the cessation of suffering, or at best a positive statement of the same, the pursuit of happiness. The motivating force of trans-modernism, the unfolding of spiritual potential through transformation, goes further. It may give us a scaffolding to arrive at those very things that motivated materialists or that fueled modernism—to find unprecedented material prosperity, unlimited longevity, etc.—but not at the expense of our ecosystem, and not limited to these things.

The path to transformation at the societal level is to deploy individually and collectively four quantum principles: discontinuity, nonlocality, downward causation, and tangled hierarchy. What does it mean to deploy these principles at the societal level, the collective level? Let's discuss three important social organizations—business, health, and religion—to explore this question.

Discontinuity

Discontinuity, as noted before, is an essential aspect of the creative process; the creative "Ah-ha!" insight is a discontinuous movement in thought. But social organizations run on continuity. Although creativity is valued in principle, the discontinuity in creativity has not been properly appreciated at the societal level. What does it mean to make room for discontinuous shifts in thought at the societal level?

Consider business, a most important part of social organization. Businesses begin from the creative vision of a person, from personal creativity. This leader then assembles a bunch of people to share his or her vision, and the vision then is manifested. But after that initial flurry of creativity, businesses bog down to mechanical repetition of produc-

tion until and unless faced with a crisis. Then a creative redefinition must take place if the business is to survive.

Instead of this current model, suppose businesses consciously install the idea of creativity, discontinuous shifts and all, to complement on a regular basis the continuous running of their operations. What then? Recall that the creative process necessitates not only work, but also relaxation to make room for unconscious processing, the proliferation of possibilities. So if businesses want to be innovative, the way to do it is to change highly pressurized and efficiency-oriented work atmospheres to more relaxed work schedules where plenty of opportunities for a relaxed approach to things are made available. One of the big problems of businesses today is employee retention. Such a shift from efficiency to a more balanced approach that focuses not only on efficiency, but also on relaxation and creativity, will also help employee retention.

Consider next medicine and healing, one of the biggest social organizations in the West. Current medical models are treatment models—treatment of disease—focusing on chemical fixing (via drugs) or mechanical fixing (via surgery) of the body. Suppose instead, we concentrate on health and healing. Health refers to wholeness in not only the physical, but also the vital, mental, and spiritual dimensions. What keeps us from wholeness in the vital, mental, and spiritual dimensions? Conditioning—imposition of imagined boundaries or structures—while being in these dimensions has no boundary, no structure. So health in these dimensions cannot be achieved without a commitment to creativity. Our vital, mental, and spiritual bodies have to be maintained not in a conditioned homeostasis, but in a dynamic equilibrium that includes creative movement, discontinuous movements.

In this way, health requires a preventive approach, rather than a treatment-of-disease approach. We do physical exercise to care for the physical body. We must complement this with preventive practices for our other bodies as well. For the vital this entails practices such as *t'ai chi*, *pranayama*, *aikido*, etc., that have come to West from China, India, and Japan respectively. For the mental, the practice of meditation is essential because it prevents the mind from the stresses of worry. For the intellect, a preventive practice is subtler. I have spoken of the flow experience in connection with creativity. We cannot take creative quantum leaps at will, but we can practice flow to keep us on the edge of creativity. And this is what keeps our intellects in dynamic balance. For the spirit, of course, nothing short of a quantum leap will do.

These quantum leaps to spiritual being are, of course, the vehicle toward a transformative wholeness that is the ultimate goal of healing.

The quantum leap to our spiritual being can also heal us from disease such as cancer. There is now substantial evidence of spontaneous remission of cancer and other diseases that the physician Deepak Chopra calls quantum healing. Chopra was the first to recognize the possible curative effect of making a quantum leap to spiritual being when the intention toward healing is clear.

Finally, let's consider spiritual organizations—organized religion. Religions give us values, no doubt. But exoteric religions prescribe only continuous methods for change, for manifesting these values in our lives. But nobody has ever become nonviolent by becoming a little less violent today, still less violent tomorrow, and so forth. So religions take refuge in the psychology of shame and guilt. Nonviolence does not come to us ex-

cept through a discontinuous transition in thought, when we realize in our being that I and my fellow creatures are one. So when religions emphasize transformation through discontinuous insights, their parishioners will gain the proper perspective for their striving towards living lives of values. Shame and guilt, quite negative emotions, will no longer be needed.

Nonlocality

What use can businesses make of quantum nonlocality? Under the influence of material realism, businesses are often conducted under sociobiological doctrines about human nature. It is assumed that humans are a competitive bunch, and therefore, competition must be the basis of running a business as well. Moreover, competition is believed to be one of the basic principles of how the market works—weeding out the unfit. Competition originates in our separateness, it is one of our ego values. In a competition-based business world, what is the use of nonlocality, which is about our interconnectedness?

Actually, it is shortsighted to think that businesses run only on competition. In truth, for creativity in business, people are often required to work in groups; and for an entire group, the areas of openness may not entirely match. Thus, there is the possibility of ego clashes that short-change much creative potential for businesses. This is especially true when the materialist worldview dominates the psyche, because then competition (dog-eats-dog) becomes a lifestyle.

In the new consciousness-based worldview, there is an answer to this problem. It is co-operation, and it happens through quantum nonlocality.

Recall that quantum nonlocality has been tested experimentally by taking advantage of what is called quantum correlation or entanglement—dancing in phase. Two objects become correlated or entangled when they interact by any local means. Once correlated, their phase-entanglement continues unbroken, even when the objects move far away from one another (only collapse can break their entanglement). So when one of the objects is collapsed by our observation of it in one place, even though at a faraway place, the other object is influenced in that the state of its collapse is locked in by the demands of the entangled dance. Aspect et al verified that this influence indeed propagates faster than the speed of light, eliminating the possibility of any local explanation.

The experiment of Grinberg et al, discussed in a previous chapter and replicated by Fenwick et al, has shown that quantum nonlocality also extends to human subjects. If two people meditate together with the conscious intention of direct communication and maintain their intention during the rest of the experiment, they become correlated and their correlation is maintained during the time of the experiment. Then, even when the two subjects are locally isolated, one brain's evoked potential (produced by a series of light flashes) is found to be nonlocally responsible for another brain's transferred potential. These experiments also show the power of conscious intention in correlating people. Consciousness is nonlocal. That is why our conscious intention can correlate us with other people. But we have to get into a meditative state, a nonordinary state of oneness, which is beyond our ordinary ego-separateness.

Now we can tackle the subject of cooperation between the strong-ego creatives working on the same project within a business. An easy way has already been suggested, but

not implemented properly. I am speaking of brainstorming–normally conducted as a discussion among creatives with suspension of disbelief in one another's half-baked ideas and with a tolerance of divergence of opinions (for example, interruptions are discouraged). But from a consciousness point of view, we can introduce a few more subtle ground rules. We can insist that people speak from silence (there is a gap between one speaker and the next), thus giving an opportunity for unconscious processing to augment conscious striving. We can also consciously guide people to the "flow" state (techniques for which are already available) before they partake in brainstorming. With the addition of these ground rules, a discussion becomes a dialogue. In Greek, *dia* means through, and *logos* means word; thus "dialogue" etymologically means "through word." Through word what? The exploration of truth through words. So what is competitive discussion in brainstorming, often resulting in showing off and grand posturing, becomes a mutual exploration of creative ideas of innovation in a dialogue.

Let's face it, though. In order to dialogue, the participants do have to discover silence within themselves, and this requires prolonged practices of meditation and other techniques of what I call inner creativity (see Chapter 23). The introduction of inner creativity in business and industry will also serve in making creative people more versatile; no longer will they have to be limited to their small windows of exploration because of their ego-boundaries. Inner creativity makes the ego boundary more fluid, flexible. The curiosity to know even extends outside the area of one's expertise, and fear gives way to love. In today's businesses, a recurring problem is the quickness with which technologies change, requiring businesses to move into new areas rapidly. So a creative versatility on the part of the employees should be most welcome for businesses.

Now we can also see how the new consciousness-based paradigm supports the ecological worldview and makes it stronger. In the ecological worldview, it is posited that when we live as part of one ecosystem, we are all interconnected (by many local interactions), and thus, we should take care of each other and our eco-environment. We should cooperate, instead of compete as the Darwinian view of us (also called sociobiology) would suggest. In the consciousness-based worldview, we are all potentially correlated, nonlocally, through consciousness. This is potentially a much stronger entanglement than the local entanglement of the ecological worldview.

The ecology movement is taking businesses in the right direction, no doubt. Its main emphasis is sustainability. Sustainability is important because when businesses operate on a sustainable energy and resource base, they become free from the shackles of a zero-sum game. Then businesses can begin to cooperate with one another, making possible a nonlocal amplification of creativity on this planet that has never happened before.

In health and healing, consideration of quantum nonlocality enters when we consider the relationship of the physician or therapist with the patient. In treatment-style medicine, physical or mental, the physician usually remains aloof and indifferent, an aspect of being objective. Unfortunately, this behavior is detrimental to the patient's well being. On the other hand, if the doctor becomes subjectively involved, that too can be harmful for the doctor, and eventually the patient also. Fortunately, there is an answer to this predicament. Aloofness in the name of objectivity is "low" indifference. One can, instead, maintain "high" indifference, which is objectivity with empathy, a nonlocal quantum connection at the level of the quantum self, where the doctor and the patient are one.

Nonlocality is also crucial in mind-body healing—for the proven power of a healing thought, of self or of another person, for releasing the body's inherent power to heal. The physician Randolph Byrd has verified in a double-blind experiment that prayer can heal even at a distance. In his experiment, some patients from a list are prayed for, while others are left as the control group, unbeknownst to the patients or even the doctors. It is found that those who were prayed for healed at a faster rate than the control group.

Finally consider the impact of nonlocality on religious practices. In exoteric popular religions, the relationship of a person with God or a higher power is denigrated to a local relationship in the form of local rituals (for example, devotion to the image of a spiritual master or to the symbol of a particular deity). This has a purpose (see below), but unfortunately, higher consciousness is nonlocal and one has to transcend the local relationship in order to arrive at truly transformative spiritual experiences. So when religious practices recognize quantum nonlocality and the true meaning of transcendence, then the dualistic separation between God and human, responsible in the main for the parochialism of organized religions, gives way to a transcendent unity of all religions.

Downward Causation and Tangled Hierarchy

In the old view "a physicist is an atom's way of knowing about itself," and "a person is a gene's way of perpetuating itself." But a mechanical atom has no need to know, let alone become transformed and wise. And a gene's perpetuation is important, but it does not require consciousness in any discernible way.

In the old view also, if you subscribe to the dualist philosophy of modernism, then the Cartesian doctrine holds for you, "I think, therefore I am." In this philosophy, we are stuck with the ego-mind, the ordinary state of our being. In the new view, with the recognition of the freedom of choice (from among the possibilities opened to us via the quantum dynamics of elementary particles and their interactions) in the event of downward causation that leads to the collapse of possibilities into actualities, the defining dictum for ourselves is, "I choose, therefore I am." And every one of us is entitled to the quantum self mode of operation where this unlimited freedom of choice is available.

But now a problem for how businesses are run today, and a genuine need for transformation. Ordinarily, in the context of businesses, people assume that power comes from outside—so the CEO is the most powerful, and an employee's power comes only from his or her usefulness to the boss. This is how a simple hierarchy operates. In a simple hierarchy, our freedom of choice is severely compromised and creativity cannot flourish.

So proper exercise of downward causation, or rather, the freedom of choice in downward causation, requires tangled hierarchy. Every employee must be free to feel the origin of power within his or her own deep self, the quantum self. With this empowerment, creativity can rise to unprecedented heights.

In materialist operation of businesses, there is only competition for power (through proving the most usefulness to the company). In the ecological worldview, power comes from cooperation, although without personal transformation, cooperation is artificial. With consciousness-as-the-ground-of-being worldview, every employee is empowered from within once the source is recognized.

With personal empowerment comes personal responsibility. This is most important

for businesses. Today, there is incessant talk about total quality. But how is total quality of a product to be achieved without the assumption of personal responsibility by those responsible for the product?

Similar considerations are important for mind-body healing. Only a tangled hierarchical relationship between physician (or therapist) and patient can empower the patient to trigger self-healing, which all healing is.

With tangled hierarchy, now you can understand the importance of having a simulated local relationship of you and God (the whole, the higher consciousness). Such an I-thou relationship, to use the philosopher Martin Buber's words, although a simple hierarchical relationship in the beginning, when allowed to become a tangled hierarchical relationship, empowers us to take quantum leap to oneness. But for most organized religions, relationships stop at simple hierarchy; all their relationships are simple hierarchical. One never discovers freedom this way.

The Question of Spirituality in Human Affairs

A much-discussed topic today is the role of spirituality in human affairs—in art, science and technology, business, humanities, and religion. When the worldview is materially based, any perceived role of spirituality in the conduct of human affairs is arbitrary, necessary only to satisfy epiphenomenal spiritual urges in ourselves. But this changes drastically when consciousness is recognized as the ground of being.

In the old view, spirituality is connected mostly with God, with a necessity for humans to delegate ultimate authority to a higher being, which, of course, must be an imagination of the human brain. In the new view, spirituality is not synonymous with the pursuit of God. Instead, spirituality is the progressive realization of freer and more joyful aspects of our being. Truly, in the new view spirituality is simply the pursuit of happiness and creativity; happiness not misunderstood as hedonistic pleasure, but happiness as the spiritual joy of unlimitedness, and creativity not only limited to the mental.

Another way of seeing the role of spirituality in the new view is to recognize once again the two-self aspect of the human being. When we identify with the individualized personal ego, we also cannot help but invite a set of values connected with the preservation of the ego: competition, objectivity, win-or-lose philosophy, homeostasis, sensory pleasures, reasoning, intellectualism, individual differences, etc. But when we rise to the quantum self identity, our values shift to such being values as subjectivity, cooperation, win-win philosophy, intuition, creativity, feeling, happiness, etc.

Most importantly, the new view does not negate the ego and its values. Just as creativity requires the encounter of ego and the quantum self, the realization of happiness (inner creativity) also requires a balanced approach between ego values and being values. Without the ego, without the scaffolding that the ego provides us to manifest greater and greater creative possibilities, where would civilization be? We would forever be discovering the wheel.

But in the new view, the value-commitment toward both ego values and being (quantum self) values must be genuine, and not mere lip service. Can a nitty-gritty human affair

such as a business succeed if it accepts spiritual values for its operation? The researcher Richard Barret has shown, on the basis of surveys involving many corporations, that when business values and employee values match, and especially when both sets of values are balanced between ego and spiritual values, then businesses and employees gain: profit goes up, employee retention (a major concern in more economically advanced countries) is enhanced, and so is customer satisfaction. The truth is that a happy employee creates a happy product, which will make a customer happy also.

The businessman Katsuhiko Yazaki has discussed the four faces of ego-values in the macro affairs of all humanity: economism (the over-reliance on expansion-based economics, which invariably fosters consumerism); nationalism (the overemphasis of national boundaries in making business policies, where in truth, we are the whole world—it has always been a global village); scientism (the over-reliance, in fact, deification of science and technology); and now-ism (forgetting future generations in making business and technological decisions). We need to develop a new economics. Instead of growth and expansion economics we need steady-state economics commensurable with sustainability. We also need to modify the purely materialistic measure of economies, namely, the gross national product. We need to make the concept of well-being the pivotal concept in the new economics (of which GNP will continue to be an important index). As societies incorporate and practice quantum nonlocality in both space and time, they will see that the protection of other nation's interests and the interests of future generations is not a choice, but is compulsory. And with the rise of the consciousness-based worldview and its incorporation in society, scientism will bite the dust.

The Evolution of Human Society

Some futurologists (influenced by the materialist worldview, no doubt) talk about the evolution of human society in terms of five phases: the hunter-gatherer phase, the agricultural phase, the industrial phase, the technological phase, and most recently, the information phase. Fortunately, other futurologists, notably Alvin Toffler, have seen the impact of worldview change on society. Toffler talks about a third wave in business that is taking place right now, with the shift of humanity toward more recognition of its interconnectedness.

The idea of the five phases of evolution of human societies misses the point. Societies shift their ways in any major aspect only when the worldview changes. So we can say the first wave of society corresponded to a spiritual worldview in which the ego values were denigrated (the hunter/gatherer society). Most of humanity lived in material misery. The second wave of society followed the advent of science and technology, beginning with the agricultural society, as the worldview began to shift from spirituality to materialism. Comfort of material living improved, but the worldview was confused, giving us the separation of spirit and science as in modernism, and the idea that "God is dead" or "God is only immanent" as in post-modernism. The ecology was endangered with extinction. And now the third wave is happening in response to the worldview change from materialism. But this time the new, spiritual, consciousness-based worldview incorporates both the ego

values and the spiritual being values, upward causation and downward causation. So this third wave should bring in balance: both human comfort and environmental quality, both homeostasis (stability) and creativity (change), both competition (ego value) and cooperation (being value). So finally, in a trans-modernist society, we will harness, using the immortal words of Teilhard de Chardin, "the energies of love." And this is the most hopeful aspect of trans-modernism.

Bibliography

Barret, R. *Liberating the Corporate Soul.* Boston: Butterworth/Heinemann, 1999.

Briggs, J. *Fire in the Crucible.* LA: Tarcher, 1990.

Byrd, R. "Positive and Therapeutic Effects of Intercessor Prayer in a Coronary Care Unit Population," *Southern Medical Journal*, vol. 81, pp. 826-829, 1988.

Chopra, D. *Quantum Healing.* NY: Bantam-Doubleday, 1990.

Goswami, A. *The Self-Aware Universe: How Consciousness Creates the Material World.* NY: Tarcher/Putnam, 1993.

Goswami, A. *Quantum Creativity: Waking Up to Our Creative Potential.* Cresskill, NJ: Hampton Press, 1999.

Yazaki, K. *Path to Liangzhi: Seeking an Eternal Philosophy.* Kyoto: Future Generations Alliance Foundation, 1994.

CHAPTER 34

Epilogue: God and the Physicists' View of Nature— An Imaginary Dialogue

Physicists today don't mention God in their books or papers. Journalists have noted this, and they refer to this inhibition as the final taboo in academia. I refer to God jokingly in my classes as "the G word."

But everything changes, and very recently we have been witnessing a thaw in the absolute prohibition on discussing God. Even Stephen Hawking mentions God in his writings, although he is a staunch believer in a material reality. A few years back, the physicist Paul Davies wrote a book called *God and the New Physics*, and the book even earned the coveted Templeton prize. This is real progress.

The truth is, modern physics grew out of the revolt against the God hypothesis as the explanation of natural phenomena. So in a book on the physicists' view of nature, it is imperative to report where physics stands today on the question of God. In Volume I of this book, I discussed from time to time how the God hypothesis was eliminated from classical physics. In this chapter, I will do the reverse. I will show that, with quantum physics and its new interpretation, the God hypothesis is making a long-deserved comeback. My arguments will be given in the form of an imaginary question-and-answer dialogue.

A. Goswami, *The Physicists' View of Nature*
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Q: What is God?

A: Yes, it is most important to start our discussion with this question. Most people, when they think of "God," think of a higher power–higher than their own egos. Some people do better; they think of God not only as a higher power, but also as a creative power. Unfortunately, they also think of this power as being outside of themselves, separate from them. Then there are, of course, influences of the monotheistic religions, many of which popularly portray God as being transcendent, and as being separate from the immanent world.

So how we conceive of God depends a lot on where we are in our spiritual evolutions. A turning-about from confusion to clarity begins when we intuit that God is our *own* creative power. God may be the answer to the question, Who am I? At this point we may become interested in mystical teachings–God is everything, both transcendent and immanent, the one ground of all being. At this point it is a matter of exploring and finding it out for ourselves.

Part of the problem is also semantics. God sounds like a person, and it is hard to overcome that tendency of thinking. When we convert the question "What is God" to "Who am I," we are allowing the possibility that the question of God is actually about the nature of our own consciousness. Of course, we can think of consciousness also dualistically–as separate from matter, or monistically–all is consciousness.

So, to summarize, there are these two ways of looking at God (or consciousness, if you want a less emotionally-loaded word), two metaphysical or ontological positions. One dualistic (the popular one), the other monistic or nondualistic.

One last comment. Some traditions make a subtle distinction between God, the agency of creation, and the ground of being, which they variously call Godhead, *Brahman*, *Tao*, etc.

Q: What does science say about these metaphysical positions? Let's be specific. We all know science scoffs at dualistic notions of God as in popular Christianity. Why?

A: If God and the world are separate, made of different substances, then how do the two worlds–the God world or God substance and the material world of material substance–interact? Their interaction needs a mediator, but where is it? And then there is the question of the conservation of energy. The energy of the material world alone is conserved. It always remains the same. But any interaction with the God world (as when God acts on this world with His creative power) would require exchange of energy involving a violation of energy conservation. It is this kind of argument, simple but elegant, that keeps scientists from endorsing dualistic religious positions.

Q: So what, then, is science's problem with the monistic, nondual metaphysics of God? Why aren't a majority of scientists embracing that position?

A: This one is subtle. Obviously, science must accept–and does–that there is only one "substance" or being in reality. Otherwise we get into the problem of dualism. The question is, is that substance matter, or is it some kind of "God substance" that is the basic being?

The success of a materialist metaphysics–the idea that everything is made of matter, including mind, consciousness, and God–now causes a conceptual quandary. Is God

needed? In the 18th century, the physicist Laplace, upon explaining astronomy on the basis of the material metaphysics alone, declared, "I do not need that [God] hypothesis." Darwin repeated the same contention in biology with his evolution theory. The biological case was made almost fool-proof with the discovery of molecular biology. In psychology, Freud, Watson, and Skinner all sang the glory of a materialist metaphysics in their revolutionary investigations. In contrast, the case for a monistic consciousness—consciousness as the ground of being—has become serious only recently within science. It will take a while before this idea catches on.

Q: Will you give us some details of the winds of change in science's worldview from material monism to a monism based on consciousness?

A: The crucial question again is, Is God needed? All scientists subscribe to the philosophy of parsimony (Occam's razor): if an idea is not needed, theoretically or experimentally or both, why use it? But in recent years, both theoretical and experimental gaps, sometimes big holes, have been found in the matter-based sciences.

First, Carl Jung found, from his case studies in psychotherapy, that therapy works better when one ventures outside of the materialist models of psychology, with concepts such as intuition (which is creative and beyond reason), collective unconscious (which is nonlocal and beyond the materalist dogma of locality), and synchronicity (which is beyond materalist models of upward causation). Later, Abraham Maslow and others discovered the same thing in their psychological study of people. The answer to "Who am I?" must involve a self beyond the behavioral ego, a transpersonal self, for those people who can be said to have "positive mental health."

Second, the materialist ontology was found to be inadequate for understanding quantum phenomena from the very inception of quantum physics. Quantum phenomena clearly show discontinuity (as in the Bohr atom) and nonlocality (as demonstrated by Aspect's celebrated experiment). And the quantum measurement problem—how quantum waves of possibility that quantum mathematics calculates for objects become experienced events—cannot be solved without the assertion of downward causation. This was first seen by the great mathematician John von Neumann. Von Neumann's ideas were originally dualistic. I made a contribution showing that the quantum measurement problem can be solved with philosophical rigor only if we assert that consciousness, not matter, is the ground of all being.

Third, Stephen Gould and Niles Eldredge discovered punctuated equilibrium in biological evolution—evolution consists of more than Darwinian, gradual variation/selection chance and necessity mechanisms. There are punctuation marks in an otherwise continuous prose of Darwinian evolution. Experimentally, they show up as the "missing links" in the fossil data. Theoretically, they point to a non-Darwinian process in evolution with a faster tempo, maybe even a discontinuity, a quantum leap.

Rupert Sheldrake made a breakthrough jump from materialist thinking by proposing nonlocal morphogenetic fields as being essential for understanding biological morphogenesis—the building of form from a one-cell embryo. More recently, I myself have been able to develop a theory in which consciousness creatively intervenes in evolution producing the quantum leaps of speciation—the punctuation marks referred to before (see Chapter 29).

My theory also nicely incorporates Sheldrake's ideas and provides the much-needed understanding of the roll of development in evolution (see Chapter 30).

Fourth, in medicine, there has been an accumulation of many cases of mind-body healing, clearly demonstrating "mind over body." But if mind is brain, then how can it cause healing? The physician Deepak Chopra was the first to suggest a model of mind-body healing by proposing that it is quantum healing and works because of the quantum nature of mind and body working on a substratum of consciousness, which is the ground of being.

Fifth, there is also much data that are classified under the label "paranormal," telepathy, survival after death and reincarnation, and such. Mainstream science still scoffs at this data. But the sheer volume of it is getting a lot of attention from the public. This data can only be accommodated within a consciousness-based science.

Sixth, I must also mention the philosopher David Chalmers' work. Chalmers pointed out that the subject-object split awareness that we experience is a "hard question" of consciousness which neurophysiologists are not studying. Maybe they cannot study it—if we start with objects or algorithms, we always have to stay at the same level: objects beget objects, and input statements beget output statements, never a subject looking at objects or a subject examining the output statement.

This is a very brief summary, of course. Many other scientists have contributed to the monistic consciousness-based paradigm that is now developing. The good news about the new paradigm is that it is inclusive. It includes the old science, via a correspondence principle. And it promises an integration of science and spirituality.

Q: But many mainstream scientists remain skeptical about any integration of science and spirituality. Why?

A: Scientists are distrustful of the consciousness-based ontology because 1) they do not see a clear epistemology—the answer to how to ***know*** the reality (God) question; and 2) they think that the methodology used in spiritual traditions involves faith, which they interpret as holding a belief system without verification. This, they think, is fundamentally against the scientific method, where skeptical inquiry is essential.

What is happening right now is that the new paradigm scientists are addressing the epistemological question within science. There are several recent books that devote a considerable effort to the epistemological question.

And frankly, most scientists just miss the spiritual methodology—the fact that it is entirely the same as the scientific methodology. The truth is, the scientific method is not fully based on rational thinking. It crucially involves creativity, creative insights of intuitive quantum leaps (see Chapter 23). And scientists, too, must begin with faith—not looked upon as a static belief system, but a conviction or an intuition of the value of the inquiry. Spiritual faith, if one looks closely, is no more than that. You inquire, "What is God?" or "Who am I?" because you have faith that reality is more than it seems at first. Both scientific and spiritual inquiry are based on our intuition that the bulk of reality is "uncommon sense," to use Robert Oppenheimer's phrase.

Q: Even mystical philosophers (Ken Wilber is a notable example) remain skeptical that science and spirituality can be or should be integrated. What is your answer to that?

A: Many mystical philosophers are taking a "wait-and-see" attitude. This is reasonable because we live in an age of fads where uncooked or half-baked ideas are shouted as loudly as any other idea. Materialists have a habit of co-opting alternative-science notions. So many new age thinkers try to co-opt spirituality with the notion of an immanent God that is consistent with materialist metaphysics.

Examples are the deep ecology movement, feminist spirituality, the so-called holographic paradigm, and so forth. This is what Wilber objects to, mainly. But as my work has emphasized, all the major advocates of the current paradigm shift embrace transcendence (nonlocality) that includes immanence.

Some philosophers, Wilber included unfortunately, also seem to hold onto the notion that science is a "lower" level of activity and cannot possibily capture the "high" level, subtle aspect of reality that mystics talk about. But my own work, Deepak Chopra's work, Abraham Maslow, Rupert Sheldrake, all these should help Wilber reexamine his position.

Q: One more question on the bridging of science and spirituality. Many mystics say that ultimately God is ineffable, only subject to direct knowing of some sort. In short, this is the mystery aspect of mysticism. Science must give objective answers to questions of reality. Can science live with a fundamental mystery?

A: Why not? In quantum physics, we are living with the notion of discontinuity every day—that there is a discontinuous movement, the collapse of the possibility wave into actual events—for which no algorithm, no mechanism, and no logic can be given. It is the same mystery that the mystics are talking about. Because there is this fundamental mystery, it is possible for there to exist freedom of choice, free will, or creativity, as I often emphasize.

Q: Okay, let's now go into the million-dollar epistemological question—how to know God? If reality is undefinable, how can we even start?

A: Let's start with some very useful East Indian thinking. I could start with mystical thought in other traditions also, for example, with the Jewish *Kabbala*, and virtually reach the same conclusions, but the East Indian tradition is the one I am most familiar with.

In East Indian thought as expressed in the *Vedanta*, reality (God or consciousness) has three epistemological aspects: existence (for which the Sanskrit word is *sat*), awareness (in Sanskrit, *chit*), and bliss (in Sanskrit, *ananda*). Since ontologically, reality is ultimately undefinable (it being the absolute cannot be expressed via concepts that are secondary), East Indians very cleverly define reality as this epistemological trio existence-awareness-bliss. We can take any one, and it will give us a method.

Q: Will you give us an illustration?

A: Take bliss. At first it seems that it lies outside of us. We eat chocolate and feel bliss; so bliss must be in the chocolate itself. But soon we notice that when we have eaten too much chocolate or when we are sad, chocolate does not seem to be all that blissful. So we begin to intuit that bliss may be an aspect of our inner reality, our consciousness.

When we make the same investigation about bliss with another human being, we make an astounding discovery. Bliss level increases when we stop objectifying our part-

ner, when we acknowledge the "otherness" (as a conscious subject) of our partner. Thus begins bhakti yoga, the yoga of devotion, a practice that dominates Christianity.

Q: Wait a minute. Isn't bhakti yoga dualistic, because you are being devoted to God as the other?

A: Yes, initially. But very soon you find that the bliss level is limited when you approach God only as separate from you. You must go to the level where God is both separate and not separate from you. But as the mystic Sri Chaitanya pointed out, this God's being both separate and inseparate is beyond our thinking mind. We have to take a creative leap for that level of understanding. In that creative leap, monism prevails. Using the quantum understanding developed in the book, we can say that it is the creative leap from a simple hierarchical relationship to a tangled hierarchical relationship.

Q: This is interesting. Will you elaborate on how one epistemologically uses awareness to investigate God?

A: The investigation of awareness is most interesting because from the beginning we see the subject (ourselves) lurking behind all the objects of experience, and we get mystified. The first tendency is to ignore the subject as an epiphenomenon and concentrate on objects, as materialists do. At the next level, when we see that the study of objects will never give us a clue about the mystery of the subject, when we are ready to tackle the hard question, we begin to meditate on awareness.

The East Indian sage Patanjali and the famous Gautama Buddha both perfected the *samadhi* path to reality using the investigation of awareness. In this, one stays with meditation itself, which is to directly meditate on awareness, to discover with a quantum leap in awareness itself (from secondary to primary awareness) that ultimately the subject-object split is illusory. As the philosopher and mystic Krishnamurthy of more modern times used to put it, one discovers that the observer is the observed. But one needs to purify one's mind; Patanjali gave us an eightfold practice, as did Buddha, although they are not identical practices.

Q: You may as well complete all the methods. How does one approach reality via the investigation of being?

A: Once again, when we begin, we get enamoured with the material level of being. Later we realize that there is also being inside, our internal experience. Then begins the question, "Who am I?" We then take the *jnana* (wisdom) path, asking "Who am I?" in more and more refined ways. For example, Descartes meditated on this question and reached the premature conclusion, "I think, therefore I am," and gave up. He lost an opportunity. If he persisted in meditation, he might have experienced consciousness beyond thought. Later the philosopher David Hume saw the limitation of Descartes' thinking, but as he himself wrote, instead of further contemplating the subject, he went to play backgammon.

It is very subtle. All the answers the mind comes up with will fall short, and we must reject them—not this, not this. You have to wait for the creative quantum leap for the answer to grow within you.

Q: In the spiritual literature of India, there is also mention of karma yoga—path of action. This is very important also in the West, being the bread and butter of the Christian tradition of Catholicism. You didn't mention karma yoga.

A: I should have. Karma yoga is another way to investigate bliss. We all act, and we act primarily to be happy. Initially, we act for our personal happiness. That is the only thing that makes sense. But suffering remains as part of our lives, and we ask, "Is there a way to end suffering?"

In karma yoga we start by giving up on the fruit of the action, we try to act without a desire for a specific outcome as much as possible, because the outcome is not within our power.

Next, we practice how to act without identifying with the doer—give up the notion that I am the doer. At this stage, karma yoga is very close to bhakti yoga: God is the real doer. At the third level, we transcend all dualities that lead to inappropriate action.

Q: I guess this is an appropriate place to ask you about good and evil. Should we not always perform good actions and stay away from evil?

A: If God, consciousness, is the ground of being, then He (It) must transcend the notions of good and evil. Ultimately, one must transcend all polarities, even good and evil, to reach unity, the whole. Because ultimately, notions of good and evil are relative; what appears to be evil from one level may actually be good from a higher, more subtle perspective, and vice versa. But, in the karma path, performing what appear to be good actions to us helps us purify ourselves; evil actions create more separateness. This is why religions emphasize good actions over evil.

Q: Why are there good and evil in the first place? Why not only good?

A: This is a subtle question and there are several level of answers. At one level, this is identical to the question of why manifestation, why the ego-separateness? Well, manifestation—and the price of experience of the manifest world that we pay—is conditioning, the ego. So we have one evil—conditioning, as opposed to the good, creativity. You can see very clearly why evil is called darkness and good light in this approach to good and evil. Conditioning leads to the darkness of ignorance, which only creativity, giving rise to the light of wisdom, can remove.

But ask yourself, Can conditioning be eliminated completely from nature? Without conditioning, we would not have a reference point. Without the ego and the use of reasoning, how can we build civilization? Civilization requires the ego-scaffolding to seek creative answers to more and more sophisticated questions. Else we stay primitive and discover the wheel over and over again.

At another level, we have to look at good and evil from the biological point of view. Biological survival, maintenance, and reproduction—evolutionary forces that maintain homeostasis through adaptation—require instincts, which are experienced as negative emotions: fear, anger, lust, etc. Then there are also good emotions, the positive emotions, love, compassion, humor, etc., which are also part of our emotional being. We cannot eliminate the "evil" emotions because then, where would we be? The answer is to transcend, or in this case transform.

Q: What does science have to say about these epistemological investigations?

A: Science is helping a great deal to show the cogency and effectiveness of the practices mentioned above, both empirically and theoretically. For example, modern empirical studies of meditation have taught us a great deal about consciousness.

I stated in Chapter 18 about how the three epistemological assertions of the idealist interpretation of quantum mechanics (namely, the universality of consciousness perceived as we approach primary awareness events, the state of unconscious processing, and pure consciousness as the ground of being) are all referred to in mystical traditions, and many mystics bear witness to these cognitions. I hope you now see that universal methods exist for anyone to verify the metaphysics of monistic idealism through epistemological inquiries following the above-mentioned paths.

Q: Will you give us an example of how modern theoretical science investigations contribute to these spiritual paths?

A: All our theoretical investigations, today and in the past, are examples of the wisdom (*jnana*) path. One always ends up with a quantum leap of insight about consciousness. I realized that consciousness is the ground of being through my attempts to solve the quantum measurement problem—how the quantum possibility wave is collapsed to actual events.

Q: One disturbing question is, How does one discern a true knower of reality from a faker? How does the enlightened being behave?

A: This is very subtle. And we are never going to find a complete answer. Because the truly "enlightened" beings, the ones who have gone all the way in pure consciousness, are not going to answer such questions in words. They would no longer have the personality to engage with such questions. So we have to answer the question through empirical studies of the behavior of enlightened people. Unfortunately, the known sample is small.

Now, today, they are many people who claim to be enlightened. Unfortunately, there seems to be a gradation among them, and there seem to be very few who have gone all the way. Even achieving the state of consciousness without a subject-object split (a state that is called *nirvikalpa samadhi* in Sanskrit) is rare, and even in those who have experienced it, some vestiges of ignorance remain for a while, to drop only with maturation. I knew one such person quite well, Franklin Merrell-Wolff. He was a radiant being, but at age 93, when his wife died, he fell apart for a while. Only the ultimate being/wisdom, which East Indians call *turiya*, can burn all ignorance, all karma, present and past. One glowing example of this level of being/wisdom in recent occurrence is Ramana Maharshi.

Most people who declare themselves enlightened do this on the basis of what East Indians call *swavikalpa samadhi*, the experience of oneness of consciousness. The individual consciousness in this experience gives way to the cosmic consciousness (as, for example, studied by the mystic and philosopher Richard Bucke). The subject-object split tends to merge, but there is still separation.

Having said all that, in my limited experience as a scientist, and also as a meditator, I would like to emphasize some of the characteristics of enlightened being that Maslow also found from his empirical study of positive mental health: creativity, unconditional

love, humor, environmental independence, happiness, etc. To this list I add two: one given by the psychiatrist Uma Krishnamurthy—radiant mental health, meaning mental health that radiates to the environment. In the presence of such being, you will feel peace, feel joy, feel playfulness. The other was given by the sage Aurobindo—these people live not by reason, but more or less by intuition, they have what Aurobindo called the intuitive mind.

Q: The final question. Is the human being the end of evolution?

A: Sri Aurobindo, whom I mentioned before, intuited that humans may be the laboratory for a later, supra-mental being. The Western thinker Teilhard de Chardin shared a similar view. I am an enthusiastic supporter of this view.

Glossary

Absorption lines: discrete frequencies absorbed by the individual atoms of a substance from the continuous spectrum of a source, showing up as dark lines in a continuous background.

Algorithm: a logical rule-bound procedure to get from step A to step B.

Ananda: bliss, spiritual joy.

Anandamaya kosha: bliss body of consciousness

Annamaya kosha: physical body.

Archetype: a Platonic idea, it sets the context of a material, vital, or mental manifestation; also, the Jungian symbol for the instincts and primordial psychic processes of the collective unconscious.

Aspect, Alain: the experimental physicist at the University of Paris-Sud acclaimed for the 1982 experiment named for him that established quantum nonlocality. This experiment is a prime example of experimental metaphysics.

Atman: the Sanskrit word for the higher cosmic self beyond ego, the quantum creative self of experience of awareness beyond ego.

Aurobindo: visionary philosopher-sage who gave us the idea of the supermind. See *Supermind.*

Awareness: the field of experience in relation to which objects of consciousness, such as external physical objects and internal mental objects such as thoughts, can be distinguished as separate from the subject. Internal awareness is akin to physical space in which material objects move.

Behaviorism: the dominant paradigm of psychology in this century, it holds that the explanation of human behavior is to be found in the history of stimulus-response-reinforcement patterns of a person.

Bhakti yoga: the yoga of love or devotion.

Binary message: a message using variables that take on one of two possible values, 0 or 1.

Blackbody radiation: radiation spectrum emitted by a perfectly black body. An ordinary incandescent solid emits basically the same spectral distribution of radiation.

Bliss body: consciousness in its infinite suchness.

Bohr, Niels: a Danish physicist, discoverer of the Bohr atom and of the complementarity principle. During his lifetime, he was the most influential spokesperson for the message of quantum mechanics.

Brahman: Sanskrit word signifying consciousness as the ground of all being; godhead or Tao.

Causal body: an alternative name for the bliss body or Brahman.

Causal determinism: see *Determinism.*

Causality: the principle that a cause precedes every effect.

Cerebral cortex: the outermost and most recently evolved segment of the mammalian brain; also called the neocortex.

Chakras: the locations in the physical body where conditioned movements of the vital energy can be felt. See also ***kundalini.***

Chaos theory: a theory of certain deterministic classical systems (called chaotic systems) whose motion is so sensitive to initial conditions as not to be susceptible to long-term predictability. To materialists, this determined but not predictable character of chaotic systems makes them an apt metaphor for subjective phenomena.

Character: the tendencies, patterns, and learned repertoire of contexts that define an individual.

Chi: the Chinese word for the modes of motion of the vital body; see also *Prana*.

Circularity: see *self reference*.

Classical mechanics: the system of physics based on Isaac Newton's laws of motion; today it remains only approximately valid for most macro objects as a special case of quantum mechanics.

Classical physics: see classical mechanics.

Collective unconscious: unitive unconscious—that aspect of our consciousness that transcends space, time, and culture, but of which we are unaware. A concept first introduced by Jung.

Complementarity: the characteristic of quantum objects possessing opposite aspects, such as waveness and particleness, only one of which we can see with a given experimental arrangement. The complementary aspects of a quantum object refer to transcendent waves and immanent particles.

Complementarity principle: that the wave and particle aspects of a quantum object are complementary; only one aspect can be measured with a given experimental arrangement.

Consciousness: the ground of being (original, self-contained, and constitutive of all things) that manifests (as appearance) as the subject that chooses, and experiences what it chooses, as it self-referentially collapses the quantum wave function in the brain or in a living cell or other cellular conglomerates.

Context: the interpretive field consciousness uses to guide the flow of meaning into the world; the underpinning behind content.

Correspondence principle: the idea, discovered by Bohr, that under certain limiting conditions (which are satisfied by most macrobodies under ordinary circumstances) quantum mathematics predicts the same motion as Newtonian classical mathematics. A similar correspondence principle is found to hold for idealist science; under conditions of complete conditioning idealist science corresponds to materialist science.

Creativity: the discovery or invention of something new of value in a new context or with new meaning.

Darwin, Charles: the discoverer of the theory of evolution that bears his name.

Darwinian evolution: evolution that progresses through slow, gradual, and continuous modifications of population.

Decay: the process in which an atomic nucleus emits harmful radiation and transforms to a different state.

Deep ecology: the ecology of interconnectedness.

Determinism: the philosophy according to which the world is causal and completely determined by Newton's laws of motion and the initial conditions—the initial positions and velocities of the objects of the space-time universe.

Discontinuity: movement for which no causal mechanism or algorithm or mathematics or logic exists.

Double-slit experiment: the classic experiment for determining characteristics of waves; a beam of light or electrons, for example, is split by passing it through two slits in a screen to make an interference pattern on a photographic plate or a fluorescent screen.

Downward Causation: the idea that consciousness, supposedly the uppermost, epiphenomenal level of material existence, exerts causal influence on matter through freedom of choice among material quantum possibilities. It is a paradox in materialist thinking.

Dualism: the idea that mind and brain belong to two separate realms of reality.

Ego: the identification with the content of an individual's story line and also habit pattern.

Einstein, Albert: perhaps the most famous physicist who ever lived, he is the discoverer of the relativity theories. He was a major contributor to quantum theory, including the basic ideas of wave-particle duality and probability.

Emission line spectrum: lines of light of discrete frequency emitted by individual atoms of a substance.

Epiphenomenon: a secondary phenomenon with no causal efficacy; something that exists contingent on the prior existence of something else.

Fluorescence: the property of some substances of absorbing light of high frequency and emitting back light of a lower frequency.

Free will: freedom of choice undetermined by any necessary cause.

Freud, Sigmund: the founder of psychoanalysis and, according to some, of modern psychology.

Gene: components of the DNA molecule that are believed to be the elements that transfer hereditary traits in reproduction; genes are also believed to be selected for or against in biological evolution; according to some biologists, the genes are the fundamental elements of biological being.

Genetic Drift: all the changes of the gene content of a population due to random chance events.

Genotype: the totality of the genes of an individual, all the genetic information.

God: the creative principle behind the totality of all manifestation.

Gunas: qualities of consciousness in ancient Indian psychology that correspond to psychological drives in more modern terminology. There are three *gunas*: *sattwa* (illumination), *rajas* (libido), and *tamas* (conditioned ignorance).

Heaven: archetypal realm; also archetypal realm of godly traits.

Heisenberg, Werner: a German physicist and co-discoverer of quantum mechanics. His discovery of quantum mechanics is widely regarded as one of the most creative events in the history of physics.

Hell: archetypal realm of consciousness corresponding to the violent emotions.

Homeostasis: the maintenance of relatively stable state of equilibrium (that is more or less constant phenotype) by an evolutionary lineage of an organism.

Idealism: the philosophy that holds that the fundamental elements of reality must include the mind as well as matter. See also *Monistic idealism*.

Idealist science: science based on the primacy of consciousness; see also *science within consciousness*.

Immanent reality: a monistic idealist's designation of the immanent space-time-matter-motion ordinary world of our experience to distinguish it from a transcendent world of ideas and archetypes; however, note that both transcendent and immanent worlds exist in consciousness, the first as possibility forms (ideas), the second as the result of a conscious observation.

Individual self: the ego-content and character together define the individual self.

Intellect: the body of themes or laws of movement of the mind, the vital, and the physical body. See also theme body.

Interference: the interaction of two waves incident in the same region of space that produces a net disturbance equal to the algebraic sum of the individual disturbances of the respective waves.

Interference pattern: the pattern of reinforcement of a wave disturbance in some places and cancellation in others that is produced by the superposition of two (or more) waves.

Irreversibility: the idea that natural (manifest) processes do not play identically when run backward in time.

Jnana yoga: the yoga based on using thought to transcend thought.

Jnanam: Sanskrit word meaning knowledge.

Jung, Carl G.: the psychologist who founded a major force of modern psychology which carries his name; he is famous for his concept of the collective unconscious and for his visionary insight that physics and psychology one day should come together.

Karma yoga: the yoga of action, a yoga in which one acts but surrenders personal interest in the fruit of the action.

Ki: the Japanese word for the modes of movement of the vital body.

Koan: a paradoxical statement or question used in the Zen Buddhist tradition to enable the mind to make a discontinuous (quantum) leap in understanding.

Kosha: Sanskrit word meaning sheath.

Kundalini: coiled up vital energy whose rising along a nadi that parallels the spine opens the chakras. See also *Chakra*.

Lamarckism: the evolutionary theory of Lamarck based on the inheritance of acquired characteristics.

Laser: a device that uses stimulated emission and the principle of standing waves in confinement to give a coherent unidirectional plane wave beam of considerable power.

Law of conservation of energy: the idea, which has been vindicated in every scientific experiment so far, that the energy of the material universe remains a constant.

Law-like behavior: behavior governed by causal laws such as the laws of physics.

Life: the identity of consciousness that results from the self-referential quantum measurement in the living cell and its conglomerates.

Locality: the idea that all interactions or communications among objects occur via fields or signals that propagate through space-time, obeying the speed-of-light limit.

Macrobodies: large-scale objects such as a baseball or a table.

Mana: Sanskrit word meaning mind.

Maslow, Abraham: the founder of transpersonal psychology, which is based on a monistic idealist framework.

Material realism: a philosophy holding that there is only one material reality, that all things are made of matter (and its correlates, energy and fields), and that consciousness is an epiphenomenon of matter.

Materialist: in this book, we have used the word materialist to mean material realist, one who holds matter to be the ground of all being.

Matter waves: material objects such as electrons and atoms (and even macrobodies) have wave-like properties, according to quantum mechanics. Waves of material objects are called matter waves.

Maya: the agency of the apparent separateness of I and the world, also translated as illusion. According to the present theory, the action of *maya* is tangled hierarchy.

Mental body: the body of mind stuff that belongs to a separate world. Mind gives meaning to brain stuff.

Meridian: Chinese concept for the pathway of the flow of chi, vital energy.

Mind: see *Mental body*.

Mind field: awareness in which thoughts move.

Monism: the philosophy that mind and brain belong to the same reality.

Monistic idealism: the philosophy that defines consciousness as the primary reality, as the ground of all being. The objects of the consensus, empirical reality are all epiphenomena of consciousness that arise from the modifications of consciousness. There is no self-nature in either the subject or the object of a conscious experience apart from consciousness.

Manamaya kosha: the mental body of consciousness.

Morphogenesis: the making of biological form.

Morphogenetic fields: the information fields that, according to Rupert Sheldrake, contain the templates of form of biological beings.

Mutation: A spontaneous (or induced) modification of a DNA sequence of a gene in an individual of an organism.

Mystical experience: an experience of consciousness in its quantum self beyond ego.

Natural Selection: the nonrandom success of a small percentage of a population to survive and reproduce due to their possession of characters that enhance their ability to survive and reproduce.

Neocortex: see *Cerebral cortex*.

Newton, Isaac: the founder of classical mechanics.

Nirvana: Sanskrit word literally meaning the extinction of the flame (of desire). It is the highest goal of spiritual practice in Buddhism.

Nonlocal correlation: also called EPR correlation. A phase relationship that persists even at a distance between two quantum objects that have interacted for a period and then stopped interacting. In the model of this book, the EPR correlation corresponds to a potential nonlocal influence between the objects.

Nonlocality: an instantaneous influence or communication without any exchange of signals through space-time; an unbroken wholeness or nonseparability that transcends space-time; see also *Transcendence*.

Nucleus: the heavy core of the atom around which electrons revolve.

Ontology: the study of the essence of being or fundamental reality; metaphysics.

Paradigm shift: a fundamental change in the supertheory or umbrella worldview that governs scientific work at a given time.

Pauli exclusion principle: the principle that no two electrons can occupy the same space or have an identical set of quantum numbers.

Phase relationship: a relationship between the phases (conditions) of motion of objects, especially waves.

Phenotype: the totality of macroscopic characteristics of an individual, its traits.

Photoelectric effect: the emission of electrons from a metal when light shines on it.

Photon: a quantum of light.

Planck's constant: a fundamental constant of nature that fixes the scale of the quantum behavior: h = 6.62×10^{-34} J/s.

Plato: one of the original monistic idealists in the West.

Potentia: the transcendent domain of the possibility waves of quantum physics.

Possibility wave: a multi-faceted quantum state with phase relations among its different facets (or possibilities). For example, an electron going through a double slit becomes a wave of two possible states, one state corresponding to its passing through slit 1 and another state corresponding to its passing through slit 2.

Prana: Sanskrit word that means vital energy (and also means breath and life).

Pranayama: a technique for watching the movement of breath; its purpose is to slow down the rate of breathing.

Pranamaya kosha: the body of consciousness made of *prana*.

Program-like behavior: behavior not only governed by cause but also by purpose, as in computer programs.

Psyche: the body of our internal experience consisting of the vital, the mental, and the intellect or theme body.

Psychokinesis: psychic ability to move things.

Psychophysical parallelism: the idea that psyche and body belong to two separate, noninteracting realities in which things happen parallelly. In other words, for every state of the brain, there is a corresponding internal state of the psyche.

Punctuated equilibrium: a theory of evolution that says there are discrete periods of rapid evolution (punctuation marks, periods and commas), within the otherwise continuous text of Darwinian evolution.

Quantum: a discrete bundle of energy; the lowest denomination of energy or other physical quantities that can be exchanged.

Quantum leap: a discontinuous transition of an electron from one atomic orbit to another without going through the intervening space between orbits.

Quantum measurement theory: the theory of how a multifaceted quantum possibility wave reduces or collapses to a single facet upon measurement. According to this author, measurement is accomplished only through conscious observation by an observer with awareness.

Quantum mechanics: a physical theory based on the idea of the quantum (a discrete amount) and quantum jumps (a discontinuous transition), first discovered in connection with atomic objects.

Quantum memory: memory based on the modification of the probability calculus of nonlinear quantum equations that govern the quantum dynamics of the brain, mind, and the vital body. As a result of this memory, the probability of recall of learned responses is enhanced.

Quantum self: the primary subject modality of the self beyond ego where resides the real freedom, creativity, and nonlocality of human experience.

Quark ultimate elementary particles of which all hadrons—strongly interacting particles—are made.

Radioactivity: the property of certain chemical elements to spontaneously emit harmful radiation while their atomic nuclei undergo decay. Radioactive decay is governed by quantum probability rules.

Rajas: the Sanskrit word for the tendency towards activeness, akin to libido, the psychological drive of Freudian vintage.

Realism: the philosophy that propounds the existence of an empirical reality independent of observers or subjects. See also *Material realism*.

Reality: all that is the case, including both local and nonlocal, immanent and transcendent; in contrast, the universe of space-time refers to the local, immanent aspect of reality.

Reductionism: the philosophy that all phenomena can be reduced to matter at some micro level.

Relativity: the theory of special relativity discovered by Einstein in 1905 that changed our concept of time from the Newtonian absolute time to a time existing in relation to motion.

Rishi: Sanskrit word meaning sage.

Samadhi, nirvikalpa: deep trance-like states of consciousness in which there is no subject-object split and yet there is creative processing.

Samadhi, swavikalpa: the experience of the quantum self that transcends ego identity.

Satchitananda: Sanskrit word signifying existence, awareness, bliss–the three fundamental epistemological aspects of consciousness.

Satori: the Zen term for *samadhi*–the experience of the quantum self.

Sattwa: the Sanskrit word for creativity, one of the psychological drives, according to Hindu psychology.

Schrödinger, Erwin: an Austrian physicist and co-discoverer with Heisenberg of quantum mechanics, he was opposed to the Copenhagen interpretation for quite some time. Later in life, he embraced some elements of the philosophy of monistic idealism.

Schrödinger equation: the fundamental equation of quantum mechanics. The solution of Schrödinger equation is called a wave function. The square of the wave function at a point of space gives the probability of finding the particle at that point.

Science within consciousness: a science based on the idea that consciousness is the ground of all being. See also *Idealist science*.

Self: the subject of consciousness. See also *individual self* and *quantum self*.

Self reference: the logical loop of an object referring to itself; also see *Circularity*.

Semantics: the study of meaning.

Sheldrake, Rupert: the biologist who propounded one of the first idealist theories of science, the theory of biological morphogenesis.

Sociobiology: science of the biological basis of social behavior.

Solipsism: the philosophy that only one's own self can be proved to exist.

Soul: the identity of consciousness with the theme or intellect body.

Species: a reproductively isolated group of populations.

Speed of light: the speed at which light travels, 300, 000 km/s; it is also the highest speed that nature allows in space-time.

States of consciousness: conditions within consciousness of varying degrees of external and internal awareness; examples are waking state, deep sleep, dream sleep, hypnosis, *samadhi* states, and so forth.

Stimulated emission: the coherent emission of an additional photon by an atom in a metastable excited state via the stimulation by an incident photon.

Supermind: the capacity of "control" over the theme or intellect body of being, including the laws of physics.

Synchronicity: acausal but meaningful coincidences, a term employed by Jung.

Tamas: a Sanskrit term meaning the tendency toward conditioned action in Hindu psychology.

Tangled hierarchy: a logical loop between levels of categories in a hierarchy that cannot be causally traced without encountering a discontinuity. An example is the liar's paradox: I am a liar.

Teleology: existence of purpose or final cause directed processes in nature.

Theme body: the body of consciousness consisting of the contexts or themes of movement of the mental, vital, and physical bodies; also called the intellect. See also *vijnanamaya kosha*.

Transcendental domain: pertaining to a realm of reality that is paradoxically both within and outside physical space-time. According to this book, the transcendent realm is to be interpreted as being nonlocal–it can influence events in space-time by making possible connections without an exchange of signals through space-time. See also *Nonlocality* and *Potentia*.

Transcendental experience: a direct experience of consciousness beyond ego.
Transpersonal psychology: the school of psychology based on the idea that our consciousness extends beyond the conditioned individual ego to include a unitive and transcendent aspect.
Turiya: consciousness in its suchness that transcends all states of consciousness.
Uncertainty principle: the principle that such complementary quantities as momentum and position of a quantum object cannot be measured simultaneously with complete accuracy.
Unconscious: in this book, the reality of which there is consciousness, but no awareness; see also *Collective unconscious*.
Unconscious perception: perception without awareness of it; in this book, perception for which there is no collapse of the quantum brain state.
Unconscious processing: processing by consciousness without the presence of awareness (that is, without the collapse of possibility waves).
Upward Causation: causation moving up from elementary particles to atoms, to molecules, to living cells including neurons, to the brain.
Vedanta: the end or final messages of the Hindu *Vedas*, also called the *Upanishads*, that propound the philosophy of monistic idealism.
Vijnanamaya kosha: the theme body of the laws of movement of the other substance bodies, physical, vital, and mental, also called the intellect.
Vital body: the body of life-processes made of life-substance (*prana* or *chi* or *ki*) as opposed to physical and mental processes; this is a body separate from and independent of the physical and the mental bodies. It contains morphogenic fields.
Vital energy: the modes of movement of the vital body; also called *prana*, *chi*, or *ki*.
Vitalism the belief that life is due to living organisms having a nonmaterial vital substance.
von Neumann, John: a mathematician who was the first to postulate that consciousness collapses the quantum wave function; he also did fundamental work in game theory and the theory of modern computers.
Wave function: a mathematical function that represents the wave amplitude of quantum possibility waves; it is obtained as a solution of the Schrödinger equation.
Wilber, Ken: transpersonal philosopher whose voluminous work has been instrumental in bringing Eastern wisdom to the Western psyche.
Zen: Japanese Buddhism.
Zygote: a fertilized egg.

Index

Absolute temperature 24
Absorption lines 76
Acausality 54 ff.
Accelerators 118
Alberts, B. 254
Alice in Wonderland 5
Alpha rays 95
Amabice, T. 217
Anthropic principle 231 ff.
Antiparticle 98, 111
Archemedes 209
Archetypes 214, 259
Aristotle 58
Arrow of time 232-233
Aspect, Alain 133 ff., 200
Atom 4 ff., 11, 35 ff., 42 ff., 73 ff., 89 ff., 107
  and chemistry 85 ff.
  and light 73 ff.
  Bohr model 35 ff., 42 ff., 209
  multielectronic 89 ff.
  Rutherford model 35
Atomic number 96
Aurobindo, Sri 301 ff., 310, 329
Autopoiesis 240, 250
Awareness 186, 211, 224 ff.

Balmer lines 75
Balmer, J.J. 74
Banerji, Ranan 226
Barret, Richard 319-320
Barrier penetration 6
Barron, Frank 213, 217
Baryon 111
Bauer, Edmond 169
Becquerrel, Henry 93
Bell inequality 34 ff.
Bell, John 133 ff.
Bell's theorem 135-136, 141
Bergson, Henry 58-59, 258
Berkeley, George 185
Beta rays 95
Bhakti yoga 326
Big bang 227 ff.
Biophysical parallelism 282 ff.
Blackbody radiation 21 ff., 65
Bohm, David 133 ff., 141 ff., 191-192, 193 ff., 210
Bohr, Niels 33 ff., 51, 55, 65, 66, 68 ff., 74-75, 142, 166, 167-168, 180 ff., 266
Born, Max 50, 66
Boson 111
Boson condensation 153
Boundary conditions 263
Brain 147 ff., 175 ff., 188 ff., 200-201, 222 ff., 274 ff.
Briggs, John 213, 326
Bubble chamber 108
Bucke, Richard 328
Buddha 208, 326
Byrd, Randolph 317, 320

Cairns, John 290 ff., 297
Campbell, Donald 204
Capra, Fritjoff 189, 192
Carbon 91
Categorical imperative 216
Causal determinism, see Determinism
Causal interpretation (Bohm's) 191
Causality 40, 67
Cell 187, 247 ff., 273 ff.
Cellular automata 250 ff.
Chadwick, James 95
Chaitanya, Sri 326
Chalmers, David 9, 83, 157, 226, 324
Chance and necessity 248
Chaos theory 12 ff., 190, 252 ff.
Chi 283 ff.
Chopra, Deepak 287-288, 320, 323
Christianity 170
Classical modality 275
Classical physics 3 ff., 21 ff., 55, 66 ff., 161, 246
Classical/quantum dichotomy 142-143
Collapse 7, 133, 140 ff., 161 ff., 167 ff., 180 ff., 191, 194, 196, 204, 211, 221 ff., 228 ff., 273, 289 ff.
Collective unconscious 214
Color of stars 23
Comings, Mark 196
Complementarity principle 51, 162
Complexity 257 ff.
Computer 210, 223, 262 ff.
Conditioning 174, 225
Conductor 119 ff.
Consciousness 7 ff., 11, 14, 54 ff., 140, 145-146, 147 ff., 161 ff., 167 ff., 184 ff., 191, 196, 204 ff., 210 ff., 220 ff., 228 ff., 237 ff., 259 ff., 269 ff., 281 ff., 289 ff., 301 ff.
Context (of meaning) 198
Continuity 67, 197, 209-210
Copenhagen interpretation 65 ff., 142, 168

Correspondence principle 61-62, 242
Covalent bond 90
CPU 147-149
Cramer, John 145
Creationism 239
Creative process 210 ff., 274
Creativity 198 ff., 207 ff., 304
  and development 213-214
  in biological evolution 289 ff.
Crystals 44, 281
Csikzentmihalyi, M. 212, 217
Curie, Marie and Pierre 94
Cytoplasm 247

D'Espagnat, Bernard 141
Dark matter 118
Davidson, Clinton 44
Davies, Paul 254, 271, 321
de Broglie, Louis 41 ff., 65, 193
de Chardin, Teilhard 307
Decoherence 140, 274
Deep ecology 189 ff.
Degeneracy 273
Delayed choice experiment 229 ff.
Democritus 107, 113
Dennett, Daniel 226
Dependent coarising 211
Descartes, René 164, 326
Determinism 3, 4, 67, 190, 246
Dick, Philip K. 144
Diffraction 43-44
Dialogue 316
Dirac, Paul 69, 162, 167
Directed mutation 241, 290 ff.
Discontinuity 39-40, 60, 192, 194, 195, 197 ff., 209-210, 270 ff., 313 ff.
Distant-viewing experiment 200, 223
DNA 239, 247, 280, 285, 291
Dobzhansky, Theodore 270, 277
Double-slit experiment 47 ff., 181 ff., 194
Downward causation 7, 172, 187, 191-192, 197 ff., 204 ff., 210, 256-257, 317 ff.
"Drawing Hands" 186
Driesch, Hans 286
Dualism 12, 145 ff., 164-165, 172, 184, 210, 219 ff., 241-242, 266, 283
Dualities 219 ff.

Eberhard, Philippe 200
Eberhard's theorem 200, 203
Eccles, John C. 226
Effron, Robert 262
Ego 174, 212 ff., 225, 318 ff.
Einstein, Albert 6, 29 ff., 43, 54, 55, 65, 69, 75, 131 ff., 199
Einstein-Podolsky-Rosen (EPR) paradox 131 ff.
Eldredge, Niles 270 ff., 323
Electron 35 ff. 42 ff., 47 ff., 87 ff., 95, 111, 113, 119 ff., 133, 181 ff.
Electron tunneling 39
Elemental Mind 151
Elementary particles 4 ff., 107 ff.
Elssasser, W.M. 273, 297
Emission lines 74
Emperor's New Mind, The 304
Energy bands 120
Energy levels 25, 36
Entropy 239-240, 260
Epicurus 113
Epiphenomenalism 11 ff., 246
Epistemology (of idealist interpretation) 174-176
Eukaryotes 247
Everett, Hugh 144
Evoked potential 16, 201 ff., 223
Evolution 269 ff., 279 ff., 301 ff.
Experimental metaphysics 15 ff.
Explicate order 141, 191, 195 ff.

Fermi pressure 92
Fermi, Enrico 99
Fermion 111
Feynman diagram 114
Feynman, Richard 52, 69, 113, 150
Flow experience 211 ff.
Fluorescence 76-77
Foster, P.L. 293, 297
Fraunhofer, Joseph 76
Free will 55, 167, 172, 191
Frequency 22
Freud, Sigmund 214
Fundamental creativity 198, 207-208
Gabor, Dennis 81
Gaia 241, 312
Galileo 169
Gamma rays 95, 108
Gandhi, Mahatma 208
Gardner, H. 217
Gauge symmetry 115 ff.
Gell-Mann, Murray 111 ff.
Gene 247
Gene mutation 273
General relativity 228
Genotype 250
God 54-55, 164, 306, 321 ff.
God and the New Physics 321
Gödel, Kurt 155
Gödel's theorem 155-156
Goldschmidt, R.B. 290
Goodwin, Brian 295
Goswami, Amit 9, 27, 63, 70, 138, 146, 176, 196, 217, 226, 233, 276, 292 ff., 320
Gould, Steven J. 270 ff., 323
Grand unified theory 117
Grant, Vernon 270
Great chain of being 304 ff.
Grinberg, Jacobo 16, 18, 200 ff., 206, 223, 226
Gruber, H. 217

Hadron 111

Half-life 94, 105
Hall, Barry 290-291, 297
Hameroff, Stuart 156-157
Hard question, The 157
Hawking, Steven 227 ff.
Heisenberg, Werner 45-46, 50, 59, 60, 65, 66, 68, 162-163, 167-168, 178-179, 210
Herbert, Nick 63, 134, 138, 151, 157, 226
Hidden variables 133 ff., 141 ff.
High energy physics 108
Higher mind 307-308
Ho, Mae Wan 294-297
Hofstadter, Douglas 172-173
Holism 12-13, 248 ff., 261 ff.
Hologram 80 ff., 214
Holography 80 ff.
Homeotic mutation 295
Huxley Julian 247
Hydrogen atom 74 ff.

Idealist interpretation 167 ff., 232
Illumined mind 307, 309
Implicate order 141, 191, 195 ff.
Indeterminacy 54 ff.
Inner creativity 207-208
Insight 210 ff.
Instrumentalism 164
Insulator 120
Intellect 304
Interconnectedness 190 ff.
Interference 44, 47 ff.
Intuitive mind 307, 309
Ionic bond 90
Irreversibility 143
Isotopes 96

Jahn, Robert 226
Jesus 203
Jhana path 326
Jung, Carl 200, 214, 310, 323

Kabbala 220, 325
Kant, Immanuel 170
Karma yoga 327
Kaufman, Stuart 253, 254
Kekule 209
Kelvin, Lord 4
Ki, see *Chi*
Kimura, M. 273, 277
Konner, Melvin 249
Krishnamurthy, Uma 329
Krishnamurti, J. 326

Lamarckism 241, 290 ff.
Lao Tsu 208
Laser 77 ff.
Lashley, Karl 82
Law-like behavior 263 ff.
Legget, Anthony 142
Leibniz, Gottfried 210, 223
Lepton 111
Life 9, 222, 238 ff., 255 ff., 273, 277, 282
Line spectra 74
Living cell, see Cell
Locality 67, 131, 246
Logical positivism 170, 220
London, Fritz 169
Lovelock, J.E. 277, 312

Macrorealism 142-143
Maharshi, Ramana 328
Many viewers theory 144-145
Many worlds theory 143 ff.
March, Robert 46, 63
Margenau, Henry 60
Margulis, Lynn 312
Marshall, Ian 153 ff.
Maslow, Abraham 267, 323
Mass number 96
Material monism 67-68, 220, 246
Material realism 3, 11, 66 ff., 140 ff., 161, 187, 220, 242
Matter wave 43 ff., 65 ff.
Maturana, Humberto 9, 226, 250, 255
Maxwell's demon 260-261
Maxwell's electromagnetic theory 24, 199
May, R. 217
Maya 170, 220
Mayr, E. 254, 270
McLintock, Barbara 292
McNeill, Louise 73, 83
Meaning 198, 210, 222, 265
Measurement apparatus 162 ff., 174, 179, 187, 221, 284
Measurement postulate 7
Mechanistic 3
Mechanistic theory of creativity 208 ff.
Meditation 215-216
Mendeleev, Dimitry 4, 85
Merrell-Wolff, Franklin 328
Meson 111, 114
Metastable state 78
Michelangelo 212
Mind 210, 222 ff.
Mitchell, Edgar 155
Modernism 189, 311 ff.
Molecular biology 245 ff.
Monistic idealism 13-14, 169 ff., 220 ff.
Monod, Jaques 243
Morphic fields, see Morphogenetic fields
Morphic resonance 281 ff.
Morphogenesis 240 ff., 264, 279 ff.
Morphogenetic fields 276
Moses 208
"My Wife and My Mother-In-Law" 62, 172

Natural selection 239, 248 ff., 274
Neo-Darwinism 238 ff., 248, 258, 269 ff., 289 ff.
Ness, Erne 189

Neurons 151 ff.
Neutral monism 170
Neutrino 111
Neutron 92, 95, 110 ff.
Neutron star 92
Newton, Isaac 3, 11, 210
Newton's laws of motion 193 ff., 199, 245-246
Nine dot problem 198
Nirvikalpa samadhi 176, 328
Nonlocality 14, 131 ff., 191 ff., 197 ff., 210, 223, 272 ff., 280 ff., 315 ff.
Nuclear fission 95, 99 ff.
Nuclear structure 100 ff.
Nucleus 4, 93 ff.

Objectivity 66-67, 246
Observer 55, 204-205, 224
Occam's razor 144
Operationalism 220
Oppenheimer 38, 40, 324
Organismic theory of creativity 209
Origin of life 228 ff.
Oscillators 24 ff.
Outer creativity 207-208
Overmind 308, 309

Pantheism 190
Paradigm 8, 245
Paradigm shift 7, 237 ff., 245
Paradox
  of relation of mathematics and physics 8
  of becoming 8-9
  of life and consciousness 9
  of Schrödinger's cat 139 ff.
  of Einstein, Podolsky, and Rosen 131 ff.
Parallel universes 143 ff.
Patanjali 326
Paths of inner creativity 215-216, 325 ff.
Pauli exclusion principle 87 ff., 91, 111
Pauli, Wolfgang 68-69, 87, 200
Penfield, Wilder 149
Penrose, Roger 155 ff., 226, 304
Periodic table 4, 85 ff.
Petard, H. 55
Phenocopies 290 ff.
Phenotype 248
Photoelectric effect 30 ff.
Photon 29 ff., 65, 134 ff.
Physical mind 307-308
Piaget, Jean 213, 217, 270
Planck, Max 24 ff., 65
Planck's constant 25, 54
Planck's law 26
Plato 143, 179-180, 220, 289
Plato's cave 180
Poincare, Henry 209
Polarization 134
Possibility waves 47 ff., 140 ff., 178
Post-modernism 311 ff.

Prana, see *Chi*
Preadaptation 276
Pribram, Karl 83
Prigogine, Ilya 143, 190, 192
Probability interpretation 50
Probability waves 50
Program-like behavior 263 ff., 281 ff.
Prokaryotes 247
Proteins 247, 291
Proton 95, 110-111, 112
Psychokinesis 204 ff., 211
Psychophysical parallelism 210, 222 ff., 281
Punctuated equilibrium 269 ff.
Purposiveness (in evolution) 240, 257 ff., 264, 276 ff.
Pythagoras 85

Quantum 5, 25
Quantum cosmology 227 ff.
Quantum creativity, see Creativity
Quantum evolution 269 ff.
Quantum field 108, 113 ff.
Quantum gravity 155 ff.
Quantum healing 287
Quantum hologram 155
Quantum jump 25 ff., 39-40, 60, 209 ff.
Quantum leap, see Quantum jump
Quantum measurement theory 59 ff., 140 ff., 162 ff., 171 ff., 194 ff., 209-210, 221 ff., 272 ff., 282 ff.
Quantum mechanics 46, 167 ff., 177 ff.
Quantum modality 275
Quantum number 87 ff.
Quantum physics 4 ff., 46, 161-162
Quantum potential 193 ff.
Quantum self 153, 173, 211 ff., 225, 318 ff.
Quantum speciation 270 ff.
Quark 103, 111 ff.

Radin, Dean 203, 206
Radioactive dating 103 ff.
Radioactive decay 54-55, 139, 184
Radioactivity 4, 6, 54-55, 93 ff., 139, 184
Random number generator 203
Reductionism 248 ff., 261 ff.
Regeneration 287
Regulation 286-287
Resonance 211, 274
Reticular formation 148
RNA 247
Rubin, Harry 296-297
Rutherford scattering 36
Rutherford, Lord 35-36, 93

Samadhi 216
Samadhi path 326
Satori 216
Schlitz, Marilyn 203, 206
Schmidt, Helmut 204-205, 211

Schrödinger equation 45-46, 178, 183 ff., 232, 266, 279
Schrödinger, Erwin 45-46, 60, 65, 139 ff., 172, 177-178, 210
Schrödinger's cat 139 ff., 183-187
Science within consciousness 205
Searle, John 217
Secondary awareness 225
Self reference 172-174, 186-187, 222, 228 ff.
Semiconductor 119 ff.
Sheldrake, Rupert 277, 279 ff., 323
Shells
  atomic 89 ff.
  nuclear 101 ff.
Simple hierarchy 205, 215
Simpson, Gaylord 269, 277
Singlet state 133-134
Situational creativity 198
Solar cell 125
Solid state physics 119 ff.
Solid state rectifier 123 ff.
Soul 306-307
Species selection 271 ff.
Spin 133
Spirit 306-307
Spirituality 190 ff., 208
SQUID 142
Squires, Evan 144
St. Paul 208
Stability
  of atoms 36, 43
  of nuclei 97 ff.
Stahl, Frank 292
Stapp, Henry 169, 194, 196, 220
Star Trek 57, 91, 149, 203
Stationary state 37 ff., 42
Stationary wave 41, 80
Statistical interpretation 141
Stimulated emission 79
String 117
Subject-object duality 172-174, 222
Superconductor 150
Supermind 308-309
Supernova 111
Swavikalpa samadhi 176, 328
Synchronicity 200
Szilard, Leo 232

Tagore, Rabindranath 207, 213
Tangled hierarchy 173 ff., 186, 188, 197 ff., 205-206, 215-216, 222, 317 ff.
Teleology 258
Thalamus 147
The Man in the High Castle 144
The Tao of Physics 150, 169
Theme body, see Intellect
Thermodynamics 24
Thermonuclear fusion 100
Todd, Denniss 292 ff.
Traits 213
Transactional interpretation 145-146
Transcendence 190
Transferred potential 16, 201 ff., 223
Transistor 125-126
Transmodernism 311 ff.
Transpersonal psychology 215
Traveling wave 41
Turing machine 252
Turiya 176, 328

Uncertainty principle 50, 54, 56 ff., 66, 133, 179, 224-225, 227, 284
  of thought 210
Unconscious 211, 214, 222
Unconscious processing 210 ff., 222, 274
Universe 227 ff.
Upanishads 190
Upward causation 3, 172, 187, 209, 257
Uranium 93 ff.

Varela, Francisco 250
Variation 248 ff.
Vedanta 170, 220, 325
Vital body 281 ff.
Vital mind 307-308
Vitalism 241, 266
von Neumann chain 162, 168, 173, 187
von Neumann, John 162 ff., 169, 187, 191, 221, 251 ff., 323
Waddington, C.H. 280, 294
Wald, George 248
Wallas, G. 217
Wave function 52 ff.
Wave packet 52, 59 ff.
Wave-particle duality 32-33, 43, 59 ff.
Weinberg, Steven 3, 117
White dwarf 92
Wigner, Eugene 165, 169, 228
Wigner's friend 165, 169 ff., 184 ff., 221
Wilber, Ken 201, 324
Wilson, Edward O. 249
Winnie the Pooh 108
Wolf, F.A. 9, 63, 146, 169
Wyller, Arne 233

Yang 182
Yazaki, Katsuhiko 319-320
Yin 182
Young, Arthur 301, 310
Yukawa, Hideki 114

Zen 15
Zeno's paradox 58-59
Zohar, Dana 153 ff.
Zukav, Gary 70